BRAIN MORPHOLOGY IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

By

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS ii

ABSTRACT v

CHAPTERS

1 INTRODUCTION AND REVIEW OF LITERATURE 1
- Introduction 1
- Review of the Literature 3
- Neurobiological Substrate of Language 8
- Specific Language Impairment 14
- Effects of Speech and Language Abilities on Reading Development 19
- Etiology of SLI 24
- Brain Morphology Studies of Individuals With Developmental Language Disabilities 32
- Purpose of Study 44

2 METHODOLOGY 49
- Subjects 49
- MRI Protocol 59
- Structures to be Assessed 61
- Reliability 66
- Analysis of Data 67

3 RESULTS 68
- Statistical Analyses 68
- Behavioral Analyses: Neurolinguistic, Cognitive and Reading Measures . . 69
- Comparative Analyses of Brain Structures and Correlational Findings Between Structures and Behavioral Measures 72
- Comparative Analyses for the Sylvian Fissure and Correlational Findings Between the Sylvian Fissure and Behavioral Measures 78
- Summary of Findings 84

4 DISCUSSION 86
- Behavioral Battery 86
- Pars Triangularis 88
- Planum Temporale 90
- Relationships Between Planar Assymmetry and Language Function 92
- Superior Temporal Gyrus 94
- Gross Brain Measurements 94
- Sylvian Fissure 95
- Heschl's Gyrus 97
- Sex Differences 98
- Neurobiological Bases of Language Impairment 99
- Clinical Implications 103

APPENDICES

A PRINTOUT FROM THE PROGRAM TO MEASURE THE PLANUM TEMPORALE 105
B PRINTOUT FROM THE PROGRAM TO MEASURE THE PARS TRIANGULARIS 107
C PRINTOUT FROM THE PROGRAM TO MEASURE THE SUPERIOR TEMPORAL GYRUS 109
D SUMMARY OF BRAIN MORPHOLOGY ASYMMETRY FINDINGS FOR CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT 110
E SUMMARY OF BRAIN MORPHOLOGY ASYMMETRY FINDINGS FOR CONTROL CHILDREN 111
F SUMMARY OF CLASSIFICATION FINDINGS FOR THE SYLVIAN FISSURE IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT 112
G SUMMARY OF CLASSIFICATION FINDINGS FOR THE SYLVIAN FISSURE IN CONTROL CHILDREN 113

REFERENCES 114

BIOGRAPHICAL SKETCH 130

Abstract of Dissertation Presented to the Graduate School
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BRAIN MORPHOLOGY IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT

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The left hemisphere has been identified as the dominant hemisphere for speech and language and a large body of evidence has amassed to support a structure-function relationship between the perisylvian structures in the left hemisphere of the brain and language functioning. The planum temporale and pars triangularis have been found to be larger in the left hemisphere than in the right. Because of the sylvian fissure's association with language, left-right asymmetry of the cerebral hemispheres has been interpreted as a neurobiological substrate for language.

One hypothesis regarding the pathogenesis of developmental language disorders suggests that impairments of language reflect an underlying neurobiological defect in the language structures of the brain. Brain morphology studies of individuals with developmental language disorders find reversed asymmetry or symmetry of the planum, although the bulk of this research has been performed on adults with dyslexia.

The purpose of this magnetic resonance imaging (MRI) study was to use quantitative and qualitative methods to compare regions of the sylvian fissure in children with language disorders and children with normal language skills. The subjects included eleven children with language disorders (males, 8; females, 3) and nineteen control children (males, 14; females, 5) between the ages of 5.6 - 13.0 years. Each subject received a neurolinguistic battery of tests and an MRI.

Children with language impairment were found to have atypical asymmetry of the perisylvian structures that subserve language. The planum temporale, pars triangularis and the posterior region of the sylvian fissure were found to be significantly different in children with language disorders when compared with matched controls. Furthermore, anomalous morphology in these language areas of the brain correlated with depressed language ability. These findings provide support for the hypothesis that language impairment is a consequence of an underlying neurobiological defect in the areas of the brain known to subserve language. Clinical implications are discussed.

CHAPTER 1
INTRODUCTION AND REVIEW OF THE LITERATURE

Introduction

The human brain is uniquely suited for the acquisition and use of language. Children from all over the world acquire the major components of their native language by the time they are three or four years of age (Gleason, 1993). The left hemisphere has been identified as the dominant hemisphere for the comprehension and expression of language. Ninety percent of the population in all cultures are right-handed and of these, about 95% are also left-hemisphere dominant for speech and language (Annett, 1985). Research has shown that the structures that subserve language surround the sylvian fissure and include the planum temporale, pars triangularis and Heschl's gyrus.

A large body of evidence underscores a structure-function relationship between language structures in the left hemisphere and language functioning. The planum temporale and pars triangularis have been found to be larger in the left hemisphere than in the right (Foundas, Leonard, Gilmore, Fennell, and Heilman, 1994; Galaburda, Sherman, Rosen, Aboitz, and Geschwind, 1985; Geschwind and Levitsky, 1968; Witelson and Pallie, 1973). Geschwind and Levitsky (1968) observed that in a sample of 100 brains, 65% showed a longer planum in the left hemisphere whereas only 11% had a longer right planum. Foundas, Leonard and Heilman (1995) studied subjects whose language was known to be localized in the left hemisphere and found leftward asymmetry of both the planum temporale and pars triangularis in all subjects. Because of the left sylvian fissure's association with language, left-right asymmetry of the cerebral hemispheres has been interpreted as a neurobiological substrate for language (Campbell and Whitaker, 1986).

Since language is neurobiologically based, it has been assumed that impairments of language reflect an underlying neurobiological defect in the language structures of the brain. Research collected within the last decade indicates that the leftward asymmetry of perisylvian structures in the normal population is not necessarily found in individuals with developmental language impairment (Jernigan, Hesselink, Sowell, and Tallal, 1991; Plante, 1991; Plante, Swisher, and Vance, 1989; Plante, Swisher, Vance, and Rapcsak, 1991). Brain morphology studies of individuals with developmental dyslexia (difficulty mapping graphemes to phonemes when reading) and specific language impairment (a breakdown in language development with no known cause) find reversed asymmetry or symmetry of the planum temporale, although the bulk of this research has been performed on adults with dyslexia (Cohen, Campbell, and Yaghmai, 1989; Galaburda, 1989; Galaburda et al., 1985; Hynd, Semrud-Clikeman, Lorys, Novey, and Eliopulos, 1990). These data suggest atypical right hemisphere dominance or lack of cerebral dominance for language in children with developmental language disorders.

Recent advances in technology have allowed for the examination of perisylvian structures in living subjects with magnetic resonance imaging (MRI). The acquired images have anatomic validity (Steinmetz, Rademacher, and Huang, 1989) and allow for the visualization of contiguous serial sections of the brain.

Despite the benefits of using magnetic resonance imaging (MRI) and the obvious relevance of studying children with disordered language, there continues to be a lack of morphometric data on the language structures in children with developmental language disorders. The purpose of this study was to use qualitative and quantitative methods to of analysis to study specific language regions of the brain in children with language impairments and in normal controls. The brain regions measured or classified from MRI include (a) planum temporale, (b) pars triangularis, (c) superior temporal gyrus, (d) Heschl's gyrus, and (e) posterior sylvian fissure.

Review of the Literature

Language

Definition of language

The American Speech-Language-Hearing Association (1983) defines language as "a complex and dynamic system of conventional symbols that is used in various modes for thought and communication" (p. 44). The production and comprehension of language can be accomplished through three modalities: oral, written, and conventionalized systems or gestures (i.e., sign language). The development of oral language is a phenomenal yet universal achievement. Children in every part of the world, regardless of the degree of grammatical or phonological complexity of the language, acquire the major components of their native language by the time they are three or four years of age (Gleason, 1993). This fact alone supports the view that the human brain is uniquely suited for the acquisition and use of language.

What does knowing a language mean? Knowing a language means being able to produce and understand an indefinite number of novel sentences -- sentences never spoken or heard before (Gleason, 1993). Young language-learning children manage to learn the basic rules of their language system without formally being taught and sometimes without proper models. Knowing a language also means being able to identify any spoken word in less than a third of a second, drawing on more than 100,000 entries stored in the mental dictionary of a typical monolingual adult (Fromkin, 1988).

Speech and Language Areas of the Brain

Despite the fact that the development of language is a universal phenomenon, it is quite a complex process nonetheless. Language must be received, either auditorily or visually, and processed. For the comprehension of spoken language, this involves hearing the stimulus, identifying the individual phonemes and attaching meaning to the phonemic sequences. The production of a verbal response involves formulating the content of the message, choosing the words to convey the intended meaning and selecting and implementing the motor plan. The left hemisphere has been identified as the dominant hemisphere for these specialized speech and language functions. Generally, cerebral dominance is considered to be the inverse of handedness. However, this relationship is far from perfect, especially in the case of left-handed individuals. Ninety percent of the population in all cultures are right-handed and of these, about 95% are also left-hemisphere dominant for speech and language abilities (Annett, 1985; Corballis, 1991). Approximately 10% of the population is left-handed while approximately two-thirds are left-hemisphere dominant for speech and language (Brookshire, 1978). The remaining 7 to 8% of left- and right-handed individuals have language functions bilaterally represented or lateralized to the right hemisphere (Geschwind and Galaburda, 1985a; Geschwind and Galaburda, 1985b; Geschwind and Galaburda, 1985c; Hardyck and Petrinovich, 1977; Satz, 1980).

Two major cortical areas have been identified as having specialized language functions. These two areas are located in the perisylvian region and include the anterior or motor speech and language area and the posterior or sensory speech and language area. These two areas have been largely identified through postmortem brain studies of patients with acquired aphasia resulting from cerebral vascular accidents. Figure 1-1 provides a diagram of the anterior and posterior speech and language areas of the brain.

The anterior speech and language area was first identified by Paul Broca in the mid-nineteenth century and is commonly referred to as Broca's area. Broca's area occupies pars triangularis and pars opercularis of the inferior frontal gyrus (also called the third frontal convolution), represented by Brodmann areas 44 and 45 in the left hemisphere. Pars triangularis is at the core of the anterior speech area and is a gyrus formed by the anterior ascending and anterior horizontal rami of the sylvian fissure. This frontal lobe area lies immediately in front of the part of the cortical motor strip devoted to the peripheral organs of speech. Broca's area is important for the formulation of the plan for directing the speech musculature in coordinated and integrated sequences of movements necessary for speech.

The posterior speech and language area lies posterior to the central sulcus in the temporal lobe. The primary auditory cortex is located on Heschl's gyrus on the superior temporal surface of the sylvian fissure and is important for the perception of auditory stimuli as it receives projections from the medial geniculate, the auditory division of the thalamus. Posterior to Heschl's gyrus on the lower bank of the sylvian fissure lies the planum temporale, which contains the auditory association cortex. The planum temporale is composed of a horizontal bank and a vertical bank. The horizontal bank of

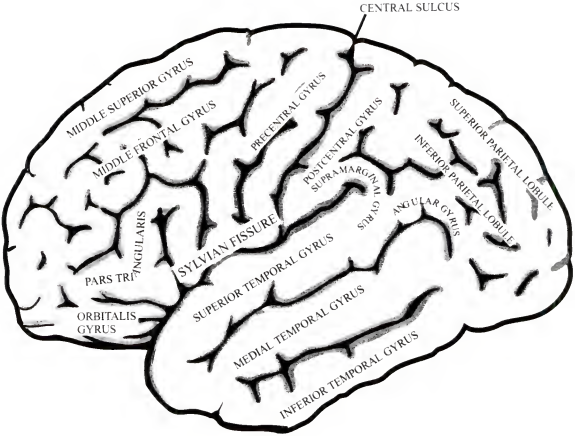


Figure 1-1. Diagram showing the anterior and posterior speech and language areas of the brain.

the planum temporale is believed to be involved with phoneme-grapheme correspondence, while the vertical bank is believed to be involved with visual-spatial skills. The planum temporale receives information from Heschl's gyrus and is important for the storage and retrieval of acoustic-phonemic "patterns" or "memories" for words. The planum temporale, together with the posterior part of the superior temporal gyrus, is the core of Wernicke's areas, represented by Brodmann area 22. Comprehension of spoken and written language takes place in Wernicke's area.

For normal language function to occur, the anterior and posterior language areas must be in communication. These two areas are connected primarily by the arcuate fasciculus, an association fiber bundle that sweeps around a region of the insula connecting Broca's area with Wernicke's area. The comprehension of speech takes place when auditory impulses are transmitted to the auditory cortex of both hemispheres and subsequently relayed to Wernicke's area in the dominant hemisphere. Similarly, the comprehension of written words takes place when visual impulses are transmitted to the visual cortex in the occipital lobes of each hemisphere and are subsequently relayed to Wernicke's area of the dominant hemisphere. When necessary, information is passed from Wernicke's area to Broca's area via the arcuate fasciculus for the formulation of the motor plan of speech movements required to formulate a verbal response. This plan is then transmitted to the motor strip where it is carried out through activation of the peripheral nervous system.

The acquired aphasias, primarily Broca's and Wernicke's aphasias, have provided heuristic data concerning the localization and lateralization of higher cortical functions. Since each of these areas functions differently for language, damage to either area produces a distinctive type of language impairment. Recent experiments comparing linguistic impairment in Broca's and Wernicke's aphasics indicate that anterior and posterior lesions do not destroy language knowledge, but rather affect language processing or access to linguistic stores in different ways (Bates, Wulfeck, and MacWhinney, 1991). The major factor differentiating the aphasias is fluency (Kimura, 1993). Broca's aphasia is also known as nonfluent aphasia. The speech of a Broca's aphasic is slow, effortful, agrammatic and often telegraphic (i.e., containing a predominance of content words such as nouns and action verbs and a paucity of adjectives, adverbs, and prepositions). However, because Wernicke's area is intact, language (listening, reading and gestural) comprehension is relatively spared. On the other hand, damage to Wernicke's area results in an impairment of language comprehension. Although the speech of Wernicke's aphasics is fluent, well-articulated and consists of phrases of normal length and prosody, the content of their language is abnormal and is contaminated by the substitution of words, parts of words and invented new words. Wernicke's aphasia is also known as fluent aphasia.

Neurobiological Substrate of Language

As noted previously, the left hemisphere is considered the dominant hemisphere for language since in most of the population, the perisylvian structures in the left hemisphere are specialized to subserve language. The notion of cerebral dominance illustrates that the brain is functionally asymmetrical since each hemisphere performs different functions. Research has indicated that in addition to functional asymmetry, the left and right hemispheres also exhibit structural asymmetry of the speech and language areas. Structural asymmetry of the language areas of the brain is observed at the gross anatomical level and at the cellular level as well as in brain maturation. Because of the left sylvian fissure's known association with language, left-right asymmetry of the cerebral hemispheres has been interpreted as a neurobiological substrate for language. Direct evidence supporting this structure-function relationship, however, is not available (Geschwind and Galaburda, 1984; Witelson, 1982).

Asymmetry of Structure

Asymmetry of the sylvian fissure has been observed in fetal brains as young as 16 weeks gestation (Chi, Dooling, and Gilles, 1977; LeMay and Culebras, 1972). Various investigators have found asymmetry in the shape and volume of the posterior and anterior regions of the sylvian fissure. Left hemisphere auditory regions have been reported to be larger than those on the right in fetuses, children and adults (Galaburda, LeMay, Kemper, and Geschwind, 1978; Musiek and Reeves, 1990). In the late 1800's, Eberstaller (1890) and Cunningham (1892) reported asymmetry of the shape of the posterior end of the sylvian fissure. Their independent studies revealed that the right fissure curls upward posteriorly and ends in a higher position than the left. Rubens, Mark, Mahowald, and Hutton (1976) later confirmed these findings and found a characteristic pattern of bifurcation of the posterior horizontal segment in 25 of 36 left hemispheres studied postmortem.

Two major classification schemes have been developed to define sylvian fissure morphology in order to quantify asymmetry of segments within the fissure. Steinmetz, Ebeling, Huang, and Khan (1990) examined 80 postmortem hemispheres as well as sagittal magnetic resonance images from 20 healthy adult volunteers and found four sylvian fissure configurations. The most commonly noted fissure configuration and the one that conforms with the anatomic "textbook" pattern is the Type 1 fissure. In the Type 1 fissure, the posterior horizontal segment of the planum bifurcates into the posterior ascending ramus (PAR). Variations of Type 1 configurations described by Steinmetz et al. (1990) are: lack of a PAR (Type 2), interposition of an intermediate opercular sulcus and gyrus between the PAR and the horizontal segment of the planum (Type 3), and lack of a supramarginal gyrus (Type 4). Steinmetz et al. (1990) reported that while the Type 1 fissure occurred in the left hemisphere about 83% of the time, it occurred in the right hemisphere only about 63% of the time. However, the Type 1 fissure was still the most frequently occurring fissure in both hemispheres. Types 2 and 3 were significantly more frequent in the left hemisphere, whereas Type 4 occurred significantly more frequently in the right hemisphere.

Witelson and Kigar (1992) later examined the sylvian fissure in 67 brain specimens and classified the fissure into 3 categories. Type H&V was the most frequently occurring type and occurred with similar frequency on both sides. In Type H&V, the horizontal segment posterior to Heschl's gyrus branches into a vertical segment (PAR). The two less frequently occurring types showed asymmetry: Type H, no bifurcation and no vertical segment, occurred mainly in the left hemisphere; Type V, anterior bifurcation and no horizontal segment, occurred most exclusively on the right side. These findings are consistent with the findings of Steinmetz et al. (1990). Both Steinmetz et al. (1990) and Witelson and Kigar (1992) developed similar classification schemes in order to quantify the shape of the sylvian fissure and found the most frequently occurring sylvian fissure configuration to consist of a horizontal segment that branches into a vertical segment.

The posterior region of the sylvian fissure that has received the most attention is the planum temporale. Since the planum temporale constitutes a large portion of Wernicke's area, asymmetry in this area may account for the predominant localization of speech and language in the left hemisphere. Geschwind and Levitsky (1968) were the first in modern times to propose a structure-function relationship between the planum temporale and language. They reported asymmetry of the planum temporale, with leftward asymmetry in 65%, symmetry in 24% and reversed asymmetry in 11% of 100 postmortem brains studied. This left-right asymmetry data has since been confirmed by many other investigators in the fetus, newborn and adult (Chi et al., 1977; C.M. Leonard, Williams, Nichols, Agee, Voeller, Honeyman, and Staab, 1993; Teszner, Tzavaras, Gruner, and Hecaen, 1972; Wada, Clarke, and Hamm, 1975; Witelson and Pallie, 1973). Specifically, research has indicated that the horizontal bank of the planum, the area thought to contain phonological maps, is typically larger in the left hemisphere and the vertical bank, the area thought to be involved with spatial attention, is typically larger on the right (C.M. Leonard et al., 1993; Steinmetz, Volkman, Jancke, and Freund, 1991; Witelson and Kigar, 1992). In a recent MRI study, planum asymmetry was associated with language dominance. Foundas et al. (1994) measured the planum temporale in 12 adults (11 right-handers and 1 non-right-hander) who had Wada testing to determine language lateralization before epilepsy surgery. All subjects who had language lateralized to the left hemisphere (11 right-handers) had leftward asymmetry of the planum. The one subject who had language lateralized to the right hemisphere (non-right-hander) had a strong rightward asymmetry of the planum. This finding is consistent with findings from a study by Blonder, Pettigrew and Smith (1994).

Planar asymmetry has also been associated with language competence. C.M. Leonard, Lombardino, Mercado, Browd, Breier, and Agee (in press) examined planar asymmetry in 40 normal children between the ages of 5 and 12 years. They reported evidence indicating that asymmetry increases gradually with age and that young children who have developed the ability to manipulate auditory symbols have significantly greater asymmetry than their less skilled peers.

The anterior border of the planum temporale, Heschl's gyrus, has also been reported to be asymmetrical in both orientation and number. Galaburda (1994) reports observing that Heschl's gyrus in the left hemisphere is more oblique than the corresponding gyrus in the right hemisphere. Also, Heschl's gyrus tends to be doubled more often on the right than on the left (Campain and Minckler, 1976).

Broca (1863) and later Eberstaller (1890) were the first to describe the anterior horizontal and ascending limbs of the sylvian fissure that make up pars triangularis in Broca's area. Eberstaller (1890) found that the ascending limb was more often branched on the left than right, and suggested that this left frontal region was more infolded and thus contained more cortex than the corresponding region on the right. Falzi, Perrone and Vignola (1982) later confirmed this assumption when they found an average of 22% more infolded cortex on the left than on the right in this area. In addition, studies have demonstrated left-right asymmetry in the length of pars triangularis. Falzi et al. (1982) found the anterior speech region of the left hemisphere to be significantly larger than the homologous area in the right hemisphere. Foundas and colleagues (Foundas et al., 1995) also reported asymmetry of pars triangularis in a study of ten epilepsy patients. All subjects in this study received the Wada test to determine language lateralization. Nine out of the 10 patients with language localized to the left hemisphere demonstrated a leftward asymmetry of pars triangularis. The one patient with language lateralized to the right demonstrated a significant rightward asymmetry of pars triangularis. Furthermore, Foundas et al. (1995) found that the direction of asymmetry for the planum was the same for pars triangularis, in that individuals with leftward asymmetry for the planum also had leftward asymmetry for pars triangularis.

Asymmetry of Cytoarchitecture

Cytoarchitectonics refers to the characteristic arrangement of neurons in different structures which render them distinguishable from their neighbors (Geschwind and Galaburda, 1984). One cytoarchitecture finding is asymmetry in the sizes of neurons in Wernicke's area. Seldon (1982) found golgi-impregnated neurons were on the average larger in the left than in the right primary auditory cortex and that this resulted in thicker columns and broader intercolumnar intervals of neurons on the left side. Hayes and Lewis (1994) reported asymmetry of Broca's area, in that the left hemisphere contained a subpopulation of magnopyramidal neurons which were significantly larger than any seen in the homotopic region of the right hemisphere.

Asymmetry of Brain Maturation

Asymmetry has also been observed in the rate of maturation of the left and right hemispheres of the brain, although there are conflicting reports as to which hemisphere is the first to develop. Evidence has been reported indicating that the right hemisphere develops earlier than the left. For example, Chi et al. (1977) found that the left planum temporale appears around the 31st week of gestation, while the right planum temporale appears a week to 10 days earlier. They also found evidence suggesting that fetal brains demonstrate earlier gyral and sulcal maturation on the right and earlier dendritic development of right Broca's area. Findings contradicting this right-left maturational gradient also exists. Thatcher, Walker, and Guidance (1987) studied the development of the cerebral hemispheres using electroencephalographic measures. They found that the left frontal-occipital and left frontal-temporal regions developed earlier than the homologous right frontal-occipital and right frontal-temporal regions.

Specific-Language Impairment

Definition of Specific-Language Impairment

While the language impairment in aphasia refers to the loss of previous language abilities, language impairment can also result from a breakdown in language development. Tallal, Ross, and Curtiss (1989) outline several reasons for the disruption in the development of language. They report that breakdown in language development can occur: (1) due to peripheral sensory (hearing loss) or motor (speech apparatus) dysfunction; (2) secondary to a more global disorder (such as mental retardation), psychiatric problems or neurological disorders (autism); and (3) secondary to postnatal brain injury to areas of the brain that subserve language. However, there remains a group of children whose language impairment cannot be explained by any of the above causes. This group of children are referred to as having "developmental dysphasia," "specific-language impairment" or "developmental language disorder."

The terms developmental dysphasia (DD), developmental language disorder (DLD), and specific-language impairment (SLI) refer to a variety of communication disorders of early childhood that are characterized by failure to acquire language normally and at the appropriate age, despite adequate hearing and nonverbal intelligence in the absence of a major sensorimotor deficit or congenital malformation of the vocal tract (Ingram, 1975; Ludlow, 1980; Myklebust, 1971; Swisher, 1985). Moreover, children with SLI show no gross signs of brain dysfunction (Rapin, 1982). This disorder is by definition a condition with no obvious cause, since the diagnosis explicitly excludes explanatory factors.

A key component in the definition of developmental language impairment, including both SLI and dyslexia, is a discrepancy between intelligence test scores (IQ) and language/reading scores, where the language/reading score is significantly lower than would be predicted by the IQ. The inclusion of this discrepancy criterion has been the cause of much controversy recently (Siegel, 1988; 1989; 1990; Stanovich, 1991). This is because most children with developmental language impairment demonstrate a low normal IQ, while the more severely impaired children demonstrate IQs below the normal range. The low IQ scores demonstrated by the children with developmental language disorders are believed to reflect the severe nature of the language deficit rather than a general cognitive deficit.

Siegel (1993) describes three conceptual problems with using IQ with children with developmental language impairment: (1) the use of IQ as an index of learning potential; (2) the appropriateness of using IQ with language-learning impaired children; and, (3) the Matthew effect. Siegel (1993) argues that the foremost problem with using IQ scores is that IQ tests, which consist primarily of measures of factual knowledge, questions about geography and history, definitions of words and memory, measure what the language impaired child has learned. She further argues that IQ tests do not measure reasoning or problem solving skills; skills which would reflect what the child has the potential to learn. Secondly, Siegel states that it is inappropriate to use IQ tests with children who have a language-learning impairment because most of these children are deficient in one or more of the component skills that are part of these tests. Therefore, the resulting IQ score would be an underestimate of the child's competence. Siegel (1993) provides the following example to illustrate this point. It is assumed that IQ test scores predict academic performance, so that a child with a low IQ score would not be expected to make major academic gains; however, in the area of reading ability, there is evidence that contradicts this assumption. Children with hyperlexia, a severe language disorder where children with very low IQ scores read words and pseudowords very well (e.g., Cobrinik, 1974; Healy, Aram, Horowitz, and Kessler, 1982; Siegel, 1984), are one example. Logically, these children should not exist if reading level was determined by IQ. Finally, Siegel (1993) sights a third issue in assessing the validity of using IQ, the "Matthew Effect" as described by Stanovich (1986). Matthew effects are a consequence of the use of certain skills. For example, children who are good at reading, read more and therefore, gain vocabulary, knowledge and language skills and, consequently obtain higher IQ scores because IQ tests measure all of these skills. Poor readers, on the other hand, show a decline in vocabulary, language and knowledge because of fewer opportunities for exposure to print. Stanovich (1986) reviewed studies that show that IQ scores decrease over time for children with reading disorders. A decline in IQ scores has also been seen in children with SLI. Jernigan et al. (1991) found that three of twenty children between the ages of 8-10 years of age had performance IQs 2 - 3 standard deviations below the normal range; a decrease from their previous IQ scores measured at 4 years of age. Francis, Espy, Rourke, and Fletcher

(1991) also site several factors affecting the validity of IQ test scores in the definition of learning disability, including psychometric problems such as determining the appropriate cut-off for deciding minimal levels of "average" intelligence and using discrepancy scores.

Prevalence of SLI

Prevalence studies estimate 8% - 15% of all preschool children are affected with some form of speech or language disorder (Beitchman, Nair, Ferguson, and Patel, 1986; Silva, 1980). A recent national survey of the case loads of speech-language pathologists working in the public schools found that 59.5% of the children they serve have a diagnosis of SLI (Carey, 1992). A growing body of evidence indicates that these children continue to demonstrate language problems and are at risk for reading and general education failure as they mature (Aram, Ekelman, and Nation, 1984; Silva, Williams, and McGee, 1987; Stevenson, 1984; Tallal, 1987). The evidence increasingly suggests that the language-delayed preschooler of today may well become the learning-disabled student of tomorrow (Snyder, 1980). Moreover, Padgett (1988) and others estimate that over half of all language-delayed preschoolers eventually show depressed reading achievement (i.e., reading ability greater than one standard deviation below that of control children).

Characteristics of SLI

Children with SLI constitute a heterogeneous group. Not all children with SLI demonstrate the same strengths and weaknesses in language. Silva et al. (1987) report three groups of children with SLI who show primary deficits in either language production, language comprehension, or both production and comprehension. Consistent with this report, Aram and Nation (1982) and Bates and Thal (1991) suggest that these children may show uneven language proficiency.

Children with SLI may perform less well across all language domains (semantics, syntax, morphology, pragmatics and phonology) compared with their normal language peers. Early studies suggest that their language development is delayed from the onset, with emergence of single words trailing behind expectations (Morley, Court, Miller, and Garside, 1955; Weeks, 1974). More recently, investigators have identified a subgroup of toddlers who demonstrate good comprehension abilities, but poor expressive vocabulary and delayed combinatorial speech at two years of age (Ratner, 1993).

Most children with SLI differ from their normal peers in their comprehension of specific word classes. Language-learning impaired children appear to have particular difficulty comprehending words that express spatial, temporal and kinship relationships (Snyder, 1984). The vast majority of children with SLI demonstrate deficits in syntactic abilities with or without accompanying comprehension deficits (Ludlow, 1980). Specifically, their abilities to use grammatical morphemes and produce a wide variety of simple and complex sentence structures are depressed when compared with those of normal peers. A subset of children with SLI also seem to experience difficulty with pragmatic functions (Leonard, 1982). They may produce less appropriate requests or respond less appropriately to the requests of others (Brinton and Fujiki, 1982; Prinz and Ferrier, 1983) and demonstrate problems with discourse, primarily in topic initiation and topic maintenance (Damico and Oller, 1980). Further, some children with SLI demonstrate expressive phonological impairment, exhibiting a limited number of speech-sound contrasts (Stoel-Gammon and Dunn, 1985), an immature sound system whereby phonological processes are not naturally eliminated (Dunn, 1986) or exhibit idiosyncratic phonological development (Grunwell, 1981).

Research has indicated, however, that SLI is more than a language delay and that these children do not simply grow out of their impairment. A high proportion of children with SLI continue to demonstrate language impairment across the domains at some level as they mature (Rescorla and Schwartz, 1990; Scarborough and Dorrich, 1990).

Effects of Speech and Language Abilities on Reading Development

Reading is a language-based skill and alphabetic reading systems require an ability to manipulate the phonological segments of language. Current literature demonstrates the importance of phonological knowledge in the development of competent readers (Apel, Shields and Perrin, 1992; Green and Edwards, 1992; Webster and Plante, 1992). Over the past eight years, research has strongly supported the tenet that children with reading impairment have underlying deficits in phonological processing. Furthermore, reading disordered children show concomitant disorders of oral language, such as deficits in speech-sound production, semantics, syntax (Kamhi and Catts, 1989).

Phonological Processing

Swank (1994) defines phonological processing as "the ability to code abstract representations of the sound attributes of spoken and written words in the form of individual units of speech known as phonemes" (p.56). The current literature indicates that deficits in phonological processing are related to reading failure in normally developing children (Frith, 1981; Liberman and Shankweiler, 1985; Wagner and Torgesen, 1987). Phonological processing abilities include phonological awareness, phonological recoding in lexical access and phonological recoding in working memory (Wagner and Torgesen, 1987). The ability to perform these linguistic operations is related to reading development (Stanovich, 1986). An individual's underlying phonological system appears to influence the development of communication and literacy skills. The phonological system includes both the representations of how to produce words and the ability to use that knowledge in the development of literacy (Hodson, 1994).

Phonological Awareness

Phonological awareness is a metalinguistic skill that entails conscious manipulation of phonemes in spoken language (Stanovich, 1986). Results of several studies in the last decade indicate that young children's phonological awareness abilities are excellent predictors of later reading and spelling performance and that children with poor phonological awareness abilities experience greater difficulty learning to read (Blachman, 1984; Bradley and Bryant, 1983, 1985; Lundberg, Olofsson, and Wall, 1980; Maclean, Bryant, and Bradley, 1987). Many researchers have found that dyslexic readers perform more poorly than nondyslexic readers on phonological awareness tasks (Fox and Routh, 1980; Montgomery, 1981; Snowling, 1980, 1981, 1985; Vellutino and Scanlon, 1987). Results of several recent studies indicate that children with current or previous expressive phonological impairments perform less well than their peers with no history of phonological difficulties (Apel et al., 1992; Green and Edwards, 1992; Webster and Plante, 1992).

Phonological Recoding in Lexical Access

Phonological recoding in lexical access involves applying grapheme-phoneme correspondence rules in order to get from a written word to its lexical referent (Liberman and Mann, 1981; Wagner and Torgesen, 1987). In other words, it involves translating the written symbol into a sound-based representational system. Tasks commonly used to access phonological recoding for lexical access involve deciding whether a string of letters represent a real word or a nonword and rapid naming of objects and colors. Phonological recoding is just one means of lexical access, the other is a more direct route from the visual pattern to its lexical referent (sight-word reading). Phonological recoding appears to be particularly important means of lexical access in the early stages of acquiring reading skills, and useful even to highly skilled readers for less familiar words (Ehri and Wilce, 1979).

Phonetic Recoding in Working Memory

Phonetic recoding in working memory involves recoding written symbols into a sound-based representational system that enables them to be maintained efficiently in working memory during ongoing processing (Baddeley, 1982). The role of efficient phonetic coding may play a vital role for beginning readers because they must decode a series of visually presented letters, store the sounds of the letters in a temporary bank, and blend the contents of the temporary store to form words. Efficient phonetic coding for storing the sounds of the letters enables the beginning reader to devote the maximum amount of cognitive resources to the difficult task of blending sounds to form words (Baddeley, 1982).

Speech-Sound Production

Deficits in the phonological processing of language are believed to disrupt the phonological aspects of speech production in some children (Catts, 1986). Catts (1986) explains that these errors occur because to produce speech correctly, one must be able to accurately encode or form phonological memory codes, reliably retrieve these codes, and correctly execute the corresponding motor programs.

Results of various studies suggest that reading disordered individuals are not as proficient as their peers when it comes to producing complex phonological sequences. Several investigators have found that the speech production errors of children with dyslexia are limited to the production of complex phonological sequences, like those found in multisyllabic words (Catts, 1986; Kamhi, Catts, and Mauer, 1990; Snowling, 1981).

Semantic-Syntactic and Phonological Language Abilities

Longitudinal studies have consistently shown that preschool and kindergarten children with speech and language impairments are at risk for reading disabilities (Bishop and Adams, 1990; Wilson and Risucci, 1980) and that children who are identified as having delayed language milestones do not attain high levels of reading and spelling when they are followed up at 7 to 8 years of age (Richman, Stevenson and Graham, 1982; Scarborough, 1995; Silva et al., 1987). Retrospective studies also report that an unusually high proportion of children with specific reading impairment were late talkers (Naidoo, 1972; Rutter, Tizard and Whitmore, 1970).

The nature of the speech-language impairment appears to be an important factor in predicting reading disabilities. Children with articulation impairments have often been reported to have normal or above normal reading abilities (Bishop and Adams, 1990). Research indicates that young children with semantic-syntactic language impairments are at higher risk for reading disabilities than are children with problems limited to articulation (Bishop and Adams, 1990; Shriberg and Kwiatkowski, 1988). Only two published studies have examined the effects of an expressive phonological impairment on later reading abilities and the results are conflicting. Bishop and Adams (1990) examined the effects of phonological impairment on later reading ability by reanalyzing data from an earlier study by Bishop and Edmundson (1986). The authors concluded that isolated phonological problems in pre-literate children were not predictive of later reading difficulties; good phonological competence was a reasonable predictor of which children would become unusually good readers, but the converse did not apply. More recently, Lewis and Freebairn (1992) employed a cross-sectional design to examine the performance of individuals with a history of preschool phonological disorder on measures of phonology, reading and spelling. In each of the three groups studied (preschool, grade school-age, and adolescence), results indicated that subjects with a history of phonological disorder performed more poorly than control subjects matched for age on reading and spelling tasks. They also found that although most of the grade school-age children and all of the adolescents and adults were considered to be normal speakers at the time of the study, they demonstrated subtle speech production deficits when their phonological systems were stressed on complex tasks such as the repetition of tongue twisters.

Etiology of Specific Language Impairment

So, what causes these otherwise normal children to demonstrate deficits in the development of language? By definition, these children do not exhibit gross anatomical abnormalities in the areas subserving language functions or exhibit any frank sensory or motor impairments that would interfere with the normal acquisition of language. There are many speculations as to the etiology of SLI, but no one explanation has been widely accepted as the underlying cause. There appear to be two primary theoretical orientations that attempt to account for the etiology of SLI; one focuses on the dysfunctional processes associated with SLI and the other on the neurobiological mechanism causing the language impairment.

Dysfunctional Processes

Leonard (1987) reviewed evidence pertaining to three prominent causal explanations of SLI: (1) a deficient communication environment, (2) difficulties perceiving rapid acoustic events, and (3) a pervasive symbolic deficit that affects nonlinguistic and linguistic areas.

Because children with SLI give the impression of being unremarkable with the exception of their language disabilities, researchers have considered the possibility that a degraded communicative environment contributes significantly to their difficulty with language. However, the fact that many children from poor language environments do not present with SLI suggests that this environmental explanation is insufficient. Wellen and Broen (1982) examined sibling interruptions in groups of children with SLI and normal language children. Their findings indicated that adults and older siblings interact with SLI children in much the same way as they interact with younger children of similar language ability, providing evidence to refute this environmental theory.

Auditory verbal deprivation in the child's home environment has been extensively investigated as a viable cause for SLI. However, a large body of research contrasting the language used by parents of language-impaired children with that of a control group has not found consistent differences (see review by Conti-Ramsden, 1985). Furthermore, studies of children in extreme environments indicate that the effects of grossly inadequate parental language can be largely compensated for by adequate experience outside the home. For example, hearing children of congenitally deaf parents are exposed to severe defective spoken language at home, yet most of them rapidly develop appropriate language skills once they go to nursery school (Critchley, 1967; Schiff, 1979). Also, there have been a few reports of children who, despite severe neglect and isolation, have made rapid progress in language development when placed in a normal environment (Skuse, 1984). Although such good outcomes are not common, these cases demonstrate that a grossly deficient language environment early in life does not necessarily result in permanent verbal impairment.

Auditory verbal deprivation can also occur due to deficient auditory stimulation arising from a fluctuating conductive hearing loss associated with chronic secretory otitis media, an infection of the middle ear. Neurophysiological studies with animals have shown that temporary deafness early in life can affect the development of neuronal interconnections in the auditory system, raising the possibility that a condition such a secretory otitis media could result in a long-term impairment in auditory functioning even after the middle ear has returned to normal (Ruben and Rapin, 1980). Otitis media is common in young children and frequently goes undetected. Although it is often assumed that the 16 to 40 dB hearing loss associated with otitis media (Bess, 1983) is not severe enough to affect language development, this degree of hearing loss can impair speech discrimination (Dobie and Berlin, 1979; Mustain, 1979).

Several studies have compared the verbal skills of children with and without histories of recurrent otitis media, but the results have been conflicting. Some find substantial differences between the groups on speech and language tests (Friel-Patti, Finitzo-Hieber, Conti, and Clinton-Brown, 1982; Silva, Kirkland, Simpson, Stewart, and Williams, 1982; Thelin, Thelin, Keith, Novak, and Keenan, 1979); while others find no differences between the groups on speech and language abilities (Brandes and Ehinger, 1981; Fischler, Todd, and Feldman, 1985; Greville, Keith, and Laven, 1985). Bishop and Edmundson (1986) compared the histories of otitis media in 69 four-year-old children with SLI with 155 children without language impairment matched on age and sex. While a significantly higher number of hospital visits for middle ear disease was reported for the language-disordered children, the groups did not differ in the number of episodes of ear infections reported. Also, comparisons of language disordered children with and without histories of recurrent otitis media revealed no differences in severity or pattern of language impairment. The authors suggested that otitis media might interact with perinatal risk factors in the etiology of language disorders, since these two factors tended to co-occur within the language-disordered group, but were not associated in the control group. Recurrent otitis media cannot be regarded as a sufficient or necessary cause of developmental language disorders since many language disordered children have no histories of otitis media and many children with otitis media demonstrate no language impairment.

The second causal explanation reviewed by Leonard (1987) involves the perception of rapid acoustic stimuli. Tallal and colleagues (Stark and Tallal, 1979, 1981; Tallal and Peircy, 1973a,b; Tallal, Stark and Curtiss, 1976; Tallal, Stark, Kallman and Mellits, 1981; Tallal, Stark and Mellits, 1985) present evidence supporting the hypothesis that a basic temporal processing impairment in language-impaired children underlies their inability to integrate sensory information which converges in rapid succession in the central nervous system. They have collected a large body of evidence that suggests that these basic temporal deficits cause a cascade of effects, starting with disruption of the normal development of an otherwise effective and efficient phonological system. The authors further propose that these phonological processing deficits result in subsequent failure in learning to speak and read normally. Although some children with SLI demonstrate such a disability, many do not (Scarborough, 1995).

A third major cause proposed to account for language disorders suggests that these children may experience subtle cognitive deficits, specifically in symbolic play and mental imagery (Johnston, 1985). This view suggests that children with SLI demonstrate symbolic deficits in nonliguistic as well as linguistic areas. Leonard (1987) refutes this as a possible cause for SLI concluding that although some of these children clearly fall below the performance level of same-age peers on these tasks, they appear to perform above the level of younger normal children with comparable language abilities. Overall, Leonard (1987) concludes that these three explanations fall short in explaining SLI because they simply describe various deficiencies in performance but fail to identify the neurobiological basis of these deficiencies.

Recently, Locke (1994) proposed a theory to explain the dysfunctional processes causing disordered language development and relate it to neurobiological evidence. He suggests that linguistic capacity develops in critically timed phases that occur gradually and sequentially. Locke claims that "when language does not develop at the usual rate, it is frequently because too little utterance material was acquired earlier, secondary to the slow maturation of species-specific neural specializations in social growth" (p. 609). Locke posits that children with developmental language delay have acquired too few utterances to activate the linguistic analytic mechanism in the left hemisphere within some hypothesized critical period for grammatical specialization. Locke further suggests that continued efforts to speak causes recruitment of perisylvian structures in the right hemisphere which have not yet terminated their growth phase and this may lead to compensatory growth of perisylvian language areas in the right hemisphere. Locke proposes that this compensatory growth may ultimately be manifested as volumetric symmetry of perisylvian areas. Although this theory is supported by neuroanatomical data in language-impaired individuals which will be reviewed below, it fails to identify the mechanism(s) that causes these children to acquire too few utterances in the first place.

Neurobiological Mechanisms

Neurobiological factors have been proposed to explain mechanisms resulting in a delay or disruption of the normal acquisition of language. Possible mechanisms proposed include chromosomal or genetic factors and sex hormone factors.

Gross chromosomal abnormalities have been examined and evidence has not been found to support this as a primary causal factor. Investigations of language-disordered children found that although there is a slight increase in the incidence of gross chromosomal disorders in this population, such abnormalities can account for only a small proportion of cases (Garvey and Mutton, 1973; Mutton and Lea, 1980; Friedrich, Dalby, Staehelin-Jensen and Bruun-Peterson, 1982). For example, a Danish group of researchers (Friedrich, Dalby, Staehelin-Jensen, and Bruun-Peterson, 1982) performed chromosome studies on 92 children with impaired language abilities and normal intelligence. Results of their study indicate that only 8 of the 92 children had gross chromosome abnormalities, such as the translocation of chromosomes or extra chromosome material.

Results of familial studies of SLI suggest, however, that the genes carried on chromosomes may play a part in the cause of SLI. The tendency for SLI to run in families suggests that there may be an inherited predisposition to such a disorder, arising from a single gene, or polygenetic influences. Several studies have reported rather consistent data demonstrating that the immediate family members of language-impaired children are much more likely to have language-impairment than the family members of non-language-impaired children (Gopnik and Crago, 1990; Neils and Aram, 1989; Tallal et al., 1989; Tomblin, 1989). Gopnik and Crago (1990) reported data on a large three generation family in which half the members have SLI. The data suggest that at least some of the cases of dysphasia are associated with an abnormality of a single dominant gene. It has been suggested that SLI might be due to genetic factors that affect the timing of neurological development in fetal life. Bishop (1987) described two possible scenarios to explain how genetic factors could ultimately lead to language impairment. One states that genetic factors could cause neuronal migration to occur outside the normal time frame, resulting in developmental brain abnormalities such as those found by Kemper (1984) that include polymicrogyria (many small gyri), ectopias (small loci of abnormally placed neurons) and dysplasias (focally distorted cortical architecture). Galaburda et al. (1985a) and Galaburda, Signoret, and Ronthal (1985b) found such abnormalities in the brains of individuals with dyslexia, and predominately in the left perisylvian areas which are evidence of migratory abnormalities during neural development. The second theory proposes that genetic factors could cause delayed myelination, thus producing a maturational lag in language skills (Bishop, 1987). Geschwind and Galaburda (1985a) have reported that although genetic factors are important for language lateralization, other factors may alter the effects of genetics and modify the direction and extent of structural differences associated with language lateralization.

Finally, another proposed possibility states that sex steroids affect intrauterine brain maturation (Geschwind and Galaburda, 1985a; Taylor, 1969). Testosterone may have a retardant effect on brain maturation and result in asymmetrical intrauterine maturation of the cerebral hemispheres causing the right hemisphere to mature earlier than the left, resulting in greater vulnerability of left hemisphere functions in boys (Geschwind and Galaburda, 1985a). Although there is no evidence for or against a lateralized cortical response to testosterone, Geschwind and Galaburda (1985a) use this theory to explain some of the functional and anatomic sex differences reported in the literature. This explanation is used to account for the increased prevalence of SLI and dyslexia in boys, which in some reports is as high as four times that in girls (Lovell, Shapton, and Warren, 1964; Rapin and Allen, 1988). Exposure to testosterone may also explain the well-recognized superiority of boys for visual-spatial tasks traditionally attributed to specialization of the right hemisphere, and of girls for verbal tasks controlled by the left hemisphere. Furthermore, this testosterone effect may explain documented sex differences in the cortical representation of language. For example, in studies of patients undergoing epilepsy surgery, electrical stimulation was found to interfere with naming over a larger portion of the perisylvian cortex in males than in females (Mateer, 1983). Witelson and Kigar (1992) suggested from their study of the sylvian fissure that the neural substrate for language and praxis may be different in the sexes and that language may be more dependent on the posterior regions in men than women. Witelson and Kigar (1992) also found that the horizontal sylvian fissure was longer in the left hemisphere in men than in women and suggested that the horizontal sylvian fissure and surrounding gyri in the left hemisphere may be differentially responsive to sexual differentiation of the brain by sex steroids in fetal life. McGlone (1980) found evidence indicating that men have greater functional asymmetry for some language tasks and spatial skills. Shaywitz, Shaywitz, Pugh, Constable, Skudlarski, Fulbright, Bronen, Fletcher, Shankweiler, Katz and Gore (1995) recently confirmed this finding in a functional magnetic resonance imaging study that revealed sex differences in the organization of the brain for language. Results of this study found that during phonological tasks, brain activation in males was lateralized to the left inferior frontal gyrus. WHile in females performing these same tasks, both the left and the right inferior frontal gyri were activated.

In conclusion, continued efforts in the study of the pathogenesis of SLI are necessary. The implication of genetic and sex hormone factors should be further explored as well as other neurobiological factors affecting language development. Only with this kind of research can the underlying cause of SLI be identified.

Brain Morphology Studies of Individuals with Developmental Language Disabilities

The overwhelming consistency of results of investigations of normal brain asymmetry indicate that the fundamental pattern of the brain includes strong asymmetry favoring structures around the left sylvian fissure. These asymmetries are believed to be vital to the development of language (Campbell and Whitaker, 1986). Because the left temporal cortex is known to be associated with language, these findings have been interpreted as reflecting a lateralized neurobiological substrate for language.

Studies of individuals with impaired language abilities have been completed to further examine brain-behavior relationships. Since language is neurobiologically based, it has been assumed that an impairment in language would reflect some underlying neurobiological defect in the language structures of the brain. Brain morphology studies of Broca's and Wernicke's areas have been completed in individuals with language impairment, including primarily those with dyslexia and, to a lesser extent, SLI. Brain morphology studies of these areas have also been completed on individuals with schizophrenia as these patients demonstrate disordered language functioning. These studies will be reviewed briefly. While early examinations of brain morphology were completed on postmortem specimens, more recent studies have been performed with magnetic resonance images (MRI) on living subjects.

Developmental Dyslexia

Individuals with dyslexia have difficulty with phonological recoding or the mapping of phonemes (sounds) to graphemes (letters) when reading. One of the primary symptoms of their reading problem is depressed phonemic awareness, or ability to manipulate sounds in words (Goswami and Bryant, 1990). The planum temporale is believed to be the site where phonemic manipulation takes place, because this area is thought to be the site where phoneme-grapheme maps are located for reading. Lateralized asymmetry in the size or detail of the phoneme-grapheme map may be associated with the well-documented leftward asymmetry in the temporal bank of the planum temporale (Geschwind and Levitsky, 1968; Witelson, 1982). Studies that examine deviations in brain morphology in developmental dyslexia are an extension of a growing body of evidence that documents reliable patterns of asymmetry in the human brain. The typical pattern of asymmetry found in the normal population is not found as often in the dyslexic population. Brain morphology studies of individuals with dyslexia can be divided into two groups; those examining a region of the sylvian fissure containing the planum and those specifically examining the planum.

Three studies have examined regions of the sylvian fissure containing the planum temporale with MRI (Duara, Kushch, Gross-Glenn, Barker, Jallad, Pascal, Loewenstein, Sheldon, Rabin, Levin, and Lubs, 1991; Kushch, Gross-Glenn, Jallad, Lubs, Rabin, Feldman, and Duara, 1993; Rumsey, Dorwart, Vermess, Denckla, Kruesi, Rapaport, 1986). Although each study defined their areas of interest differently, all three studies reported symmetry of the region containing the planum temporale. Rumsey et al. (1986) reported that nine out of ten dyslexic adults had symmetrical volumes of the temporal lobe examined on coronal sections. Duara et al. (1991) found symmetry of their identified region containing the planum temporale when studying the brains of 21 dyslexics. Measurements were made on axial slices. Finally, Kushch et al. (1993) replicated these findings and found symmetry of the superior surface of the temporal lobe in 12 of 17 dyslexic brains examined on coronal sections.

Galaburda and colleagues (Galaburda, 1989; Galaburda et al., 1985a) were the first to perform postmortem examinations of the planum temporale in brains of individuals with dyslexia. All 8 dyslexic brains studied had symmetrical plana due to increased size on the right and most showed evidence of migratory abnormalities during neural development.

MRI studies examining the planum temporale have not always found interhemispheric symmetry of the plana. Two independent studies in 1990 reported symmetry of the planum temporale in dyslexia. Hynd and colleagues (Hynd, Semrud-Clikeman, Lorys, Novey, and Eliopulos, 1990) and Larson and colleagues (Larson, Hoien, Lundberg, and Odegaard, 1990) both reported symmetrical plana, but unlike the Galaburda studies (Galaburda, 1989; Galaburda et al., 1985a), found it to be due to decreased size of the left planum temporale. C.M. Leonard et al. (1993) separately measured the temporal and parietal banks of the planum. Contrary to previously reported findings, C.M. Leonard and co-workers (C.M. Leonard, Voeller, Lombardino, Morris, Hynd, Alexander, Anderson, Garofalakis, Honeymen, Mao, Agee, and Staab, 1993) found that the subjects with dyslexia in their study did not have interhemispheric symmetry of the temporal bank of the planum, the part of the planum where leftward asymmetry correlates with functional localization for language (Steinmetz, Rademacher, Jancke, Huang, Thron, and Zilles, 1990; Witelson and Kigar, 1992; Foundas et al., 1994). In fact, they found that the dyslexics had exaggerated asymmetry, owing to a significant shift of right planar tissue from the temporal to parietal bank. They also found that the subjects with dyslexia were more likely to have cerebral anomalies such as missing or duplicated gyri bilaterally in the planum. Another more recent study also reported leftward asymmetry in the dyslexic population. Schultz, Cho, Staib, Kier, Fletcher, Shaywitz, Shankweiler, Katz, Gore, Duncan, and Shaywitz (1994) found no significant differences between the dyslexics and nondyslexics in symmetry of the planum after controlling for age and overall brain size. Thirteen of the 17 dyslexic boys in their study demonstrated leftward asymmetry of the planum.

Overall, these studies of brain morphology in dyslexic individuals reveal inconsistent results. While examinations of designated regions containing the planum in the left and right hemispheres seem to find interhemispheric symmetry rather consistently, examinations of the planum itself do not yield such consistent findings. The planum in individuals with dyslexia has been described as having a leftward asymmetry, a rightward asymmetry and no asymmetry. Perhaps these discrepancies are due to differences in the shape of the planum in the left and right hemispheres and methodological differences in defining boundaries in the horizontal and vertical bank of the planum.

Specific Language Impairment

Studies of brain morphology in children with SLI are far fewer than studies with children who have developmental dyslexia. While both dyslexia and SLI are developmentally language based diagnoses, few researchers have sought out children with predominant oral language deficits. As in the dyslexia research, brain morphology studies of individuals with SLI are of two types: those examining a defined region containing the planum and those directly examining the planum.

All but one brain morphology study in the SLI literature examined entire perisylvian regions containing the planum. Jernigan, Tallal, and Hesselink (1987) reported on the first study of children with language impairment. They used MRI to examine cerebral regions posterior to the sylvian fissure. Although the measured regions were not confined to those typically associated with language functioning, a higher prevalence of rightward asymmetry of defined regions posterior to the sylvian fissure was reported for the language-impaired subjects than for the control subjects. Jernigan, along with co-workers (Jernigan, Hesselink, Sowell and Tallal, 1991) later completed another similar MRI study on 20 language-learning impaired (LLI) children to measure hemispheric volumes and cerebral asymmetry. Their data indicate that the LLI children showed abnormal asymmetry of the prefrontal region (right-greater-than-left) and the parietal region (left-greater-than-right). Contrary to earlier findings, they reported that the area containing the planum in the SLI children was not significantly different in size from that area in the controls. However, the SLI subjects showed more variable asymmetry and decreased volume in this area bilaterally.

In a series of studies, Plante and colleagues (Plante, 1991; Plante, Swisher, and Vance, 1989; Plante, Swisher, Vance and Rapcsal, 1991) also used MRI to study brain morphology in children with SLI. In their first study, Plante et al. (1989) examined perisylvian areas containing the planum in a set of dizygotic twins (male and female). The area studied contained portions of the frontal and parietal operculae, the superior temporal gyrus and the planum temporale. The twins were 4.9 years of age at the time of the study, and the male was diagnosed with SLI. Both children exhibited atypical perisylvian configuration. The male's configuration was symmetrical and the female demonstrated right-greater-than-left asymmetry. Also, they reported atypical hemispheric asymmetry for the SLI male child, in that the volume of his left hemisphere was greater than that of his right hemisphere. This finding was not reported in any of the fifteen volunteers. Later, Plante et al. (1991) measured the same perisylvian region described above in 8 boys with SLI between the ages of 4.2 and 9.6 years of age. Six of the 8 boys had symmetry or reversed asymmetry of the perisylvian region. In the SLIs with reversed asymmetry, Plante et al. (1991) found that the asymmetry was due to a larger right region, not a smaller left region. These results are consistent with Galaburda (1989) and Galaburda et al. (1985a). Plante (1991) extended this earlier research to include the parents and siblings of 4 SLI boys previously studies (Plante et al., 1991). Results of this MRI examination revealed that 7 of the 8 parents and 4 of the 5 siblings had atypical perisylvian asymmetry (reversed asymmetry or symmetrical plana). Plante et al. (1991) concluded that these findings suggest that atypical perisylvian asymmetry reflect a transmittable, biological factor that places some families at risk for language impairment.

The only reported case of neuropathological findings of the planum temporale in a child with SLI was described by Cohen, Campbell, and Yaghmai (1989). The subject, a 7-year-old girl, contracted infectious mononucleosis and died of kidney and liver failure. At her time of death, she was being treated for developmental dysphasia and attention deficit disorder with hyperactivity. Postmortem examination of her brain revealed symmetry of the planum temporale and a dysplastic microgyrus on the inferior surface of the left frontal cortex along the inferior surface of the sylvian fissure. The authors report that these anomalies are likely to be related to errors in neuronal migration.

In conclusion, research examining brain morphology in individuals with dyslexia and SLI indicate that individuals with developmental language disorders do not consistently show the same leftward asymmetry as demonstrated by the normal controls. However, far too few subjects with SLI have been studied to draw conclusions. The evidence reviewed in this paper does link structural asymmetry to language functioning. Foundas et al. (1994) found leftward asymmetry of the planum temporale in patients whose language is supported by the left hemisphere and reversed asymmetry of the planum temporale in one patient whose language is supported by the right hemisphere. A second case of reversed asymmetry in a patient with right hemisphere language was also reported by Blonder, Pettigrew and Smith (1994). Finally, asymmetry of the planum temporale has been found to be reduced in children with developmental language disorders (Galaburda, 1989; Plante et al., 1991; Hynd et al., 1990).

Schizophrenia

Brain morphology studies of the anterior superior temporal gyrus have been completed on individuals with schizophrenia because these patients constitute a distinct population demonstrating disordered language functioning. Schizophrenia is a disabling psychiatric disease characterized by disordered thinking, hallucinations and disorganized speech. Auditory hallucinations are a hallmark symptom of this disease, although their cause is unknown. Results of recent neuropsychological and MRI studies suggest that the left cerebral hemisphere is compromised in schizophrenia (Barta, Pearlson, Powers, Richards and Tune, 1990; Cannon and Marco, 1994; Gautier, Kuldau, Weiss, Leonard, and Mancuso, 1995; Shenton, Kikinis, Jolesz, Pollak, LeMay, Wible, Hokama, Martin, Metcalf, Coleman, and McCarley, 1992). Cannon and Marco (1994) found schizophrenics and their nonschizophrenic siblings to have neuropsychological impairment compared with normal controls. Specifically, they found the schizophrenic patients to be more impaired in language functions than in spatial abilities. MRI findings indicate abnormalities of the left anterior superior temporal gyrus which contains the left auditory association cortex may be the cause of the auditory hallucinations and impaired language functioning. In an MRI study, Barta et al. (1990) found the anterior superior temporal gyrus to be smaller bilaterally in patients with schizophrenia compared with normal controls and a positive correlation between left anterior superior temporal gyrus atrophy and severity of auditory hallucinations. In another MRI study, Shenton et al. (1992) found the left superior temporal gyrus to be significantly smaller in schizophrenic patients when compared to normal controls and a strong negative correlation between total thought disorder score (a measure of hallucinations and delusions) and the absolute volume of the left posterior superior temporal gyrus. Gautier et al. (1995) recently confirmed these findings. The schizophrenic patients in their study showed a significantly smaller left anterior superior temporal gyrus and significantly impaired phonemic awareness compared with control subjects.

Methodological Considerations

Most of the brain morphology research reviewed in this paper was completed using MRI technology with only a few studies performed on postmortem specimens.

Both types of research indicate that similar results can be obtained whether measuring a structure from an actual specimen or an MRI. Despite the differences in measuring procedure, some of the same methodological factors should be considered when reviewing data and extrapolating the results from either type of studies. In review of the brain morphology literature of individuals with SLI and dyslexia, several methodological issues need to be considered, such as (1) use of control groups; (2) report of behavioral testing; (3) report of interrater reliability; and (4) definition of symmetry/asymmetry. Additionally, technical considerations of MRI studies include, (1) type of slice used for measuring; (2) thickness of slice used for measuring; and (3) tesla power of MRI scanner.

The use of a control group and its appropriateness are crucial factors when contrasting groups of subjects with controls. It is important when delineating deviations in asymmetry of language impaired brains to use a control group because it is necessary to have an understanding of the range of variability in the normal population before determining what is outside the normal range. Furthermore, a comparison is more meaningful when data are collected at the same center and using the same procedures for measurement on both a control group and experimental group. Although most of the studies described above included a control group, the ratio of subjects to controls was sometimes quite low, usually about 1:1.5 or 1:1. While Rumsey et al. (1986) and Galaburda et al. (1985a) did not use control groups, Larson et al. (1990) matched 19 dyslexics to 19 controls, Schultz et al. (1994) matched 17 dyslexics to 14 controls and Jernigan et al. (1991) matched 20 LLI to 12 controls. A better ratio of subjects to controls is demonstrated in the Hynd et al. (1990) and C.M. Leonard et al. (1993)

studies. Hynd et al. (1990) included 20 controls (10 children with attention deficit disorder and 10 nondyslexics) in their study of 10 dyslexics. In the C.M. Leonard et al. (1993) study, for 9 dyslexic subjects, they included 22 controls (10 unaffected first and second degree relatives and 12 normal controls).

The report of behavioral testing data is another important factor when reviewing results and conclusions from a study. A major drawback in using postmortem brains is that usually there is a lack of behavioral testing data available. Such was the case for Galaburda (1989), although his specimens were presumed to be dyslexic since they were donated by the Orton Dyslexia Society. Most studies have reported some behavioral data for subjects and controls, documenting how controls represent the normal population and how well the subjects fit their diagnosis (Plante et al., 1989, 1991; Jernigan et al., 1991). However, Duara et al. (1991) did not report IQ data for their controls. Additionally, in the Cohen et al. (1989) case study, IQ data was not consistent with the diagnosis. While their subject was diagnosed as developmentally dysphasic, she had an IQ that was inconsistent with the diagnosis of SLI (full scale IQ of 71, a verbal IQ of 70 and a performance IQ of 74). Along these same lines, Schultz et al. (1994) reported IQ data that were not representative of the normal population in their control group. The mean IQ reported for the controls in their study was almost 2 standard deviations above that of the normal population.

Interrater reliability is an important factor when determining the reliability of measurements. It is crucial that measurements from at least two independent raters be obtained and compared to document reliability of measurement technique and data reported. Most of the studies reviewed in this paper reported high reliability coefficients.

Plante (1989) and Plante et al. (1991) assessed reliability of measurement data on at least half of all subjects using the Pearson Product Moment Correlation. They reported *r* values ranging from .92 to .99. Kushch et al. (1993) reported .90 or better reliability on a sample of 5 cases, while Hynd et al. (1990), Schultz et al. (1994) and Duara et al. (1991) reported reliability coefficients of .95, .98 and .98, respectively, on their measurements. C.M. Leonard et al. (1993) reported reliability of measurements by comparing the measurements of two independent raters. When average measurements did not agree within 10%, a conference was held and the measurements were redone. In contrast, Jernigan et al. (1991) and Rumsey et al. (1986) did not report reliability data.

A definition of what is considered symmetrical and asymmetrical is important when comparing brain morphology data. Galaburda (1989) used an arbitrary criterion (1 to 2 mm) for asymmetry. In contrast, C.M. Leonard et al. (1993) used an interhemispheric coefficient formula to determine asymmetry of the temporal, parietal and total planum and an intrahemispheric coefficient of asymmetry formula to determine asymmetry of the left and right hemispheres. The advantage of this type of definition is that an average can be calculated for each brain structure measured. Plante (1989) and Plante et al. (1991) defined their criteria of symmetry/asymmetry in a different way. They calculated a measure of perisylvian asymmetry, defined as right perisylvian volume/left perisylvian volume. Using their formula, perfect asymmetry produces a quotient of 1.00, quotients exceeding 1.05 are classified as right greater than left, and quotients less than 0.95 are classified as left greater than right. Cohen et al. (1989) did not define their criteria for asymmetry.

Improvements with MRI have allowed for the visualization of contiguous serial sections of the brain in living subjects using volumetric acquisitions. Measurements made of the planum on sagittal images of postmortem specimens have anatomic validity in that they have been found to correlate highly with planar size measured on photographs of the same specimens (Steinmetz et al., 1989). Sagittal sections appear to be the best sections for measuring the planum because it allows for the visualization of entire extent of the structure, however, only C.M. Leonard et al. (1993) has used this slice section in their study of brain morphology in individuals with dyslexia. Other researchers have used coronal sections (Schultz et al., 1994; Larson et al., 1990; Kushch et al., 1993) or axial sections (Duara et al., 1991).

Thickness of slice used in volumetric measuring affects how many measurements can be made on a particular structure, thus affecting the preciseness of measurements. A related important factor is the gap between slices used for measuring. Of the published research to date, C.M. Leonard et al. (1993) used the thinnest section slices (1.25 mm) in a gapless series. This is contrasted with Jernigan et al. (1991) who used 5 mm thick sections separated by a 2.5 mm gap.

Tesla represents the strength of the scanner; the higher the Tesla number, the higher the contrast to noise ratio, resulting in clearer and more defined structures on the images. Tesla power in the studies reviewed ranged from .5 Tesla (Plante, 1989; Plante et al., 1991; Rumsey et al., 1986) to 1.5 Tesla (Duara et al., 1991; Jernigan et al., 1991; Kushch et al., 1993; Larson et al., 1991; Schultz et al., 1994).

Overall, it can be seen that these studies vary in many methodological factors. Because of this variability, caution must be exercised when generalizing these data within subject populations.

Purpose of Study

Based on the research presented, it can be concluded that the human brain is characterized by leftward asymmetry of perisylvian structures. Leftward asymmetry has been documented in the length of the planum temporale and pars triangularis as well as in the size and shape of Heschl's gyrus and the posterior portion of the sylvian fissure (Chi et al., 1977; Galaburda et al., 1985a; Geschwind and Levitsky, 1968; Foundas et al., 1994; Musiek and Reeves, 1990). This structural asymmetry is related to functional asymmetry of language and is demonstrated in studies of cerebral dominance. It is widely known that in most of the population, the left hemisphere is considered the dominant one because language is located in this hemisphere. Because of the left sylvian fissure's known association with language, left-right asymmetry of this structure has been interpreted as a neurobiological substrate for language.

Several studies examining brain morphology of individuals with developmental language impairment do not find this left-right asymmetry as consistently as it is found in the non-language impaired populations. Most of the brains in individuals with language disorders show rightward asymmetry or symmetry of the planum temporale, possibly indicating atypical right hemisphere dominance or lack of dominance for language (Cohen et al., 1989; Galaburda, 1989; Galaburda et al., 1985a; Hynd et al., 1990; Larson et al., 1990). Only a few studies have examined brain morphology in the SLI population. The examination of brain morphology in perisylvian structures such as the planum temporale, pars triangularis and Heschl's gyrus in SLI children is a logical extension of previous research on brain morphology in developmental dyslexia. Thus, the purpose of this study was to use quantitative and qualitative methods to describe regions of the sylvian fissure in children with SLI and in normal controls. Quantitative analyses of the planum temporale, pars triangularis, and the superior temporal gyrus were performed along with qualitative analyses of Heschl's gyrus and the posterior sylvian fissure.

The specific questions addressed in this research follow:

1. Do children with SLI show atypical patterns of asymmetry of pars triangularis compared with control children matched for age, sex and handedness? Since all children with SLI show some disruption of expressive language (Ludlow, 1980), it as expected that these children would demonstrate differences in structural asymmetry of pars triangularis when compared with normal controls. Foundas et al. (1994) found leftward asymmetry of pars triangularis in 9 out of 10 adult subjects with epilepsy who had language lateralized to the left hemisphere. Additionally, they found that the direction of asymmetry of the planum was the same for the pars triangularis, in that individuals with leftward asymmetry of the planum also had leftward asymmetry of pars triangularis. Pars triangularis has not been studied in children with developmental language disorders.
2. Do children with SLI show atypical patterns of planar asymmetry compared with control children matched for age, sex and handedness? Since most children with SLI have some degree of receptive language dysfunction (Snyder, 1980), it was expected that the children with SLI would not show the typical leftward

asymmetry of the planum temporale and instead show symmetry or reversed asymmetry of the planum temporale. Cohen et al. (1989), in a postmortem study of a 7-year-old girl diagnosed with developmental dysphasia, reported finding symmetry of the left and right planum temporale. This is the only reported study of the planum temporale in a child with SLI.

3. Does degree of asymmetry of pars triangularis correlate with language ability? Because of the expressive language deficits demonstrated by children with SLI (Ludlow, 1980) and the function of pars triangularis in the expressive language, it was expected that the degree of atypical asymmetry would correlate with language ability. While pars triangularis has not been examined in children with developmental language disorders, findings of studies of pars triangularis in normal adult patients who have language functions specialized to the left hemisphere indicate a relationship between asymmetry of pars triangularis and language localization (Foundas et al., 1994).

4. Does degree of asymmetry of the planum temporale correlate with language ability? Because of the receptive language deficits demonstrated by children with SLI (Snyder, 1980) and the function of the planum temporale in receptive language, it was expected that the degree of atypical asymmetry would correlate with language ability. This question has not been addressed in the brain morphology literature of children with SLI. However, Larson et al. (1990) found that subjects with dyslexia who demonstrated pure phonological deficits in reading had symmetrical plana. In normal children, C.M. Leonard et al. (in press) found that asymmetry increased gradually with age and that young children who have

developed phonemic awareness skills have significantly greater asymmetry than their less skilled peers.

5. Does the shape of the posterior sylvian fissure correlate with language ability? Because the structures in the brain that subserve language are located in the perisylvian region, it was expected that atypical sylvian fissure configurations would correlate with low comprehension scores. In their study of adults with dyslexia, C.M. Leonard et al. (1993) found that 6 out of 9 subjects had anomalous sylvian fissures (5 occurrences on the left and 1 on the right) as defined by Steinmetz, Ebeling, Huang, and Kahn (1990).

6. Does the shape of Heschl's gyrus correlate with language ability? Because the primary auditory cortex is located on Heschl's gyrus, it was expected that anomalies of Heschl's gyrus in the SLI population would correlate with low scores in phonemic awareness. In their study of adults with dyslexia, C.M. Leonard et al. (1993) found that 4 out of 9 subjects had multiple Heschl's gyri (MH) (1 occurrence of MH on the left; 2 on the right; 1 bilaterally). Heschl's gyrus has not been examined in the SLI population.

7. Does asymmetry of the anterior superior temporal gyrus correlate with language ability? Because the auditory association area is located on both the anterior and posterior superior temporal gyrus, it was expected that atypical asymmetry of the anterior superior temporal gyrus would correlate with impaired language scores. Three studies of schizophrenic subjects, Barta et al. (1990), Gautier et al. (1995) and Shenton et al. (1992) found that the left anterior superior temporal gyrus was

significantly smaller than the right superior temporal gyrus compared with control subjects.

CHAPTER 2
METHODOLOGY

The purpose of the present study was to use quantitative and qualitative methods to compare regions of the sylvian fissure in children with specific language impairment (SLI) and children without language impairment. The goal of this study was to determine if children with deficient language abilities have anomalous morphology in the areas of the brain known to subserve language. Qualitative analyses were performed on the posterior region of the sylvian fissure and Heschl's gyrus. Quantitative analyses were performed on the planum temporale, pars triangularis and the superior temporal gyrus. Gross measurements of the hemispheres and the corpus callosum were also made and analyzed.

Subjects

Recruitment of Subjects with SLI

Eleven subjects (males, 8; females, 3; mean age, 9.0 years, range 5.8 - 13.0 years) with SLI participated in this study. Table 2-1 provides a description of subjects. In cooperation with speech-language pathologists in the Alachua County Public Schools, the Ross-Mercer Clinic at the University of Florida and the University of Florida Speech and Hearing Clinic, subjects were solicited who met the following criteria: (a) adequate intellectual functioning for nonverbal cognitive and academic skills as determined by psychoeducational testing and/or teacher reports and school placement; (b) a diagnosis of a speech and/or language impairment by a certified speech-language pathologist; (c) hearing within normal limits as indicated by school records of hearing screenings (20 dB at 500, 1000, 2000 and 4000 Hz) and normal corrected vision; (d) absence of behavioral problems or diagnosed emotional/psychiatric disorders; and (e) absence of a history of neurological impairment.

Table 2-1. Characteristics of Children with Specific Language Impairment (SLI) and Control Children.

Variable	SLI Group	Control Group
Number of subjects	11	19
Sex, M/F	8/3	14/5
Quantitative handedness, mean ± SD	0.75 ± 0.55	0.75 ± 0.46
Age, mean ± SD	9.1 ± 2.3	8.9 ± 1.6
TONI, mean ± SD	92 ± 11.1	102 ± 8.9

TONI = Test of Nonverbal Intelligence

Subjects who met these criteria were given letters to take home to their parents explaining the study. The parents were asked to contact the project investigators if they were interested in having their child participate in the study. Telephone screenings were performed with each parent who responded to the letter to confirm potential eligibility and to further explain the study. Subjects who met the above criteria were scheduled for a language evaluation to confirm the diagnosis of SLI.

Confirmation of Diagnosis

After the subjects and their parents read and signed an Informed Consent Form approved by the University of Florida Institutional Review Board, a neurolinguistic battery of tests was used to assess each subject's language functioning. Aram and

Nation's (1982) Child Language Processing Model (CLPM) was used as a framework for choosing the standardized tests to evaluate children for specific-language impairment. This model is well suited for use in neurobiological studies of language learning disabilities because it allows for the assessment of all levels of language processing and production that have shown anatomic-clinical correlations in studies of brain-injured children (Aram and Ekelman, 1986; Aram, Ekelman, and Whitaker, 1986; Aram, Ekelman, and Whitaker, 1987). In this model, the behavioral correlates of speech perception, phonology, semantics, syntax, pragmatics and speech production are associated with specific processing stages (pre-linguistic, linguistic, and post-linguistic). The neurolinguistic battery of tests developed for this study was designed to reflect: (a) the major stages of processing and the behavioral domains identified in the CLPM; (b) instruments appropriate for the age of the clinical population to be studied; and, (c) procedures found to provide adequate clinical utility for diagnosing language disorders. An attempt was made to choose standardized tests that yield standard scores.

Neurolinguistic Battery

1. Five subtests of the Clinical Evaluation of Language Fundamentals-Revised (CELF-R) (Semel, Wiig, and Secord, 1987) were used to assess expressive and receptive language skills.

   Sentence Structure - This subtest assesses the ability to comprehend sentence structure by pointing to the appropriate picture from a choice of four that corresponds to the sentence auditorily presented by the examiner.

Oral Directions - The subtest assesses the comprehension, recall, and execution of oral commands presented by the examiner of increasing length and linguistic complexity.

Formulated Sentences - This subtest assesses the formulation of simple, compound and complex sentences. The subject is given a word and asked to use that word in a complete sentence.

Recalling Sentences - This subtest assesses recall and reproduction of surface structure as a function of syntactic complexity. The subject is asked to repeat the sentence the examiner auditorily presents.

Word Associations - This subtest assesses the ability to recall labels for members of a semantic class within a time limit. For example, the subject is given 60 seconds to tell the examiner the names of as many animals as he/she can.

2. One subtest of the Test of Language Development-Primary 2 (TOLD-P2) (Newcomer and Hammill, 1988) was used to assess the child's level of expressive morphology. This subtest was administered only to those subjects who were between the ages of 4.0 and 8.11 years.

   Grammatic Completion - This subtest assesses the ability to recognize, understand, and use common morphological forms, with particular emphasis on the knowledge of inflections. The examiner reads aloud unfinished sentences and the child supplies the missing morphological form.

3. Two subtests of the Test of Language Development-Intermediate (TOLD-I) (Hammill and Newcomer, 1982) were used to assess receptive semantics and

syntax. These subtests were administered only to those subjects who were between the ages of 8.6 - 12.11 years.

Characteristics - This subtest assesses the ability to understand both the meanings of and the relationships between the content words included in sentences spoken by the examiner. For example, the child was instructed to decide whether statements such as "All trees are oaks" and "All cows are brown" are true or false.

Grammatic Comprehension - This subtest assesses the ability to recognize incorrect grammar in spoken sentences. The examiner read aloud a sentence and the subject decided if the sentences was correct or incorrect.

4. The Expressive One Word Picture Vocabulary Test - Revised (EOWPVT-R) (Gardner, 1990) assesses the child's expressive vocabulary or ability to produce the name of an object or group of objects.

In addition to the language measures, the Test of Nonverbal Intelligence (TONI) (Brown, Sherbenou, and Johnsen, 1982) was administered. This test was developed to be a language free measure of cognitive ability. This test is specifically suited to evaluate the potential of individuals who are language impaired since it is entirely free of spoken and written language.

All children who performed below one standard deviation of the mean standard score on two or more tests or subtests included in the neurolinguistic battery were diagnosed as SLI and scheduled for a magnetic resonance imaging (MRI) scan of the brain. It was expected that most SLI children would score within the normal range of the mean standard score (SS) on the TONI ($SS \geq 85$); however, SLI children with severe language disorders were expected to demonstrate IQ scores below the normal range on the TONI.

Subject Selection Considerations for SLI Participants

The SLI children in this study present with a range of language impairments from mild to severe. As discussed previously, Siegel (1993) and Francis et al. (1991) point out several conceptual and psychometric problems with the use of IQ scores with children with learning disabilities. For these reasons, in this study the results of the TONI did not preclude a child from receiving a diagnosis of SLI if the child had previously been diagnosed as SLI and did not exhibit a profile consistent with criteria for the diagnosis of mentally handicapped. The definition of mentally handicapped used is: "(a) significantly subaverage general intellectual functioning: an IQ of 70 or below on an individually administered IQ test, and (b) concurrent deficits or impairments in adaptive behavior, the person's age being taken into consideration" (DSM-III, 1980). None of the children included as SLI subjects in this study with below average IQ scores demonstrated impairments in adaptive behavior. The mean nonverbal intelligence scores for both groups of children (Table 2-2) were within the normal range, however the SLI children scored, on average, 10 points below the control children. The 10 point discrepancy described is largely due to the nonverbal score of one SLI subject (F, 8.0) that was significantly below the normal range (SS = 65). For another SLI subject (F, 5.10), a nonverbal score could not be derived because a basal score was not obtained on the TONI. The researcher was confident that both children fit the diagnosis of SLI despite their nonverbal IQ data: neither demonstrated impairment in adaptive behavior as outlined in the above definition of mentally handicapped, and both children have had extensive neuropsychological and language assessments by independent professionals to confirm their diagnoses.

The profile of one SLI child (M, 11.3) contrasted markedly with the two children discussed above. This subject presented with behavioral test data that indicates a mild form of SLI. He performed below one standard deviation of the mean for his age on two neurolinguistic measures, more than two standard deviations of the mean for his age on a reading comprehension subtest, and presents with a history of academic difficulties. Based on these findings it was concluded that this subject's language abilities are consistent with established criteria of SLI.

Finally, one other SLI subject (M, 10.1), a former client in the UFSHC for several years, did not receive the same neurolinguistic battery as the other subjects. However, results from the Woodcock-Johnson Psycho-Educational Battery (Woodcock and Johnson, 1989) confirm his previous diagnosis of specific language impairment. While this subject has made significant gains in therapy, he continues to demonstrate a language impairment.

Recruitment of Control Subjects

Nineteen children (males, 14; females, 5; mean age, 8.9 years, range 5.6 - 11.11 years) served as control children in this study. See Table 2-1 for a description of control subjects. Initial eligibility criteria included: (1) absence of a history of learning and/or language disability; and (2) grade level performance in all academic areas as determined by classroom teachers. Letters specifying eligibility criteria and explaining the study were distributed to all students between the ages of 5 and 12 years in regular education classrooms at P.K. Yonge School, a laboratory school affiliated with the University of

Table 2-2. Individual Behavioral Test Data for Children with Specific Language Impairment (SLI).

Test	F 8.0	M 7.9	M 7.9	M 11.3	M 12.1	F 5.10	F 7.6	M 9.8	M 7.2	M 13.0	M 10.1*
GC	3	5	3	12	9	4	6	4	4	7	--
CH	†	†	†	7	7	†	†	6	†	5	--
RS	3	3	3	8	9	3	5	6	3	5	--
FS	3	5	4	6	11	3	4	3	3	3	--
OD	3	4	6	9	8	4	6	4	3	3	--
SS	4	6	5	9	8	4	6	4	3	3	--
WA	3	7	8	10	--	6	4	8	4	--	--
EV	<55	89	100	121	†	60	82	112	87	--	--
PC	43	77	102	78	88	‡	85	63	85	60	--
RA	62	77	115	99	88	‡	108	78	93	60	98
WI	54	87	120	94	79	‡	102	44	85	54	--
LA	0	27	28	91	63	‡	72	47	0	52	88
TO	65	96	84	95	95	‡	93	108	96	93	96§

GC = Grammatic Comprehension; CH = Characteristics; RS = Recalling Sentences; FS = Formulated Sentences; OD = Oral Directions; SS = Sentence Structure; WA = Word Associations; EV = Expressive Vocabulary; PC = Passage Comprehension; RA = Word Attack; WI = Word Identification; LA = Lindamood Auditory Conceptualization Test; TO = Test of Nonverbal Intelligence.

Standard scores reported for GC and CH (Test of Language Development) and RS, FS, OD, SS, and WA (Clinical Evaluation of Language Fundamentals - Revised) are based on a mean of 10 and a standard deviation of 3; Standard scores reported for EV (Expressive One Word Picture Vocabulary Test-Revised) and PC, RA and WI (Woodcock Reading Mastery Test-Revised) are based on a mean of 100 and a standard deviation of 15; Raw data are reported for LA;

-- subtest not administered;

* This child was also given the Woodcock-Johnson Psycho-Educational Battery (Woodcock and Johnson, 1988); scores were 461 for verbal ability and 470 for written language; 500 represents a level of performance approximately equal to that expected for his age.

† subtest not given because not appropriate for age;

‡ could not get basal on subtest;

§ this IQ score is from the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974).

Florida College of Education, and The Family Worship Center, a small private Christian school attended primarily by children from low socioeconomic backgrounds. Both schools are located in Gainesville, Florida. Telephone screenings were conducted to insure that all potential subjects had normal developmental histories and were functioning on grade level. Subjects who met the above stated criteria were scheduled for a language evaluation. After receiving signed informed consent forms from the parents and subjects, the same neurolinguistic battery and nonverbal intelligence test used to determine SLI eligibility were used to determine normal language abilities in the control children. In addition, a family history questionnaire was filled out by each family participating in the study to document any familial histories of oral and/or written learning disabilities. Subjects who scored within one standard deviation of the mean standard score on the neurolinguistic battery and nonverbal intelligence test (SS ≥ 85) were included as control children and scheduled for an MRI.

Supplemental Battery

Each subject who qualified as an SLI or control subject also received a supplemental battery to measure reading skills, phonemic awareness and hand dominance.

1. The Lindamood Auditory Conceptualization Test (LACT) (Lindamood and Lindamood, 1979) was used to assess phonemic awareness by having an individual use colored blocks to represent phonemes in simple and complex nonsense syllables. Phonemic awareness is a necessary skill in reading and spelling. This test was standardized on 660 kindergarten through 12 grade students. Percentages are available for students at each grade level who fall into various levels on the test and for students at each total test score range having

grade level or above performance in reading and spelling. After 6th grade, subjects are expected to score between 99 and 100. Leonard et al. (in press) found performance on the LACT correlated highly with planar asymmetry in a study of normal children.

2. Three subtests of the Woodcock Reading Mastery Test - Revised (WRMT-R) (Woodcock, 1987) were used to assess reading ability. These subtests were included because of the documented evidence of lack of leftward asymmetry of the planum in the brain morphology research of individuals with dyslexia.

   Word Identification - This subtest requires the subject to identify isolated words that appear in the test book. The subject is given 5 seconds to identify each word. The words are arranged in order of difficulty.

   Word Attack - This subtest measures the subject's ability to apply phonics rules to pronounce unfamiliar nonsense words.

   Passage Comprehension - This subtest measures the subject's ability to read a short passage and provide a key word missing from the passage. This subtest requires the subject to exercise a variety of comprehension and vocabulary skills.

3. A performance inventory modified from Briggs, Nebes, and Kinsbourne (1976) was used to measure hand preference. The performance inventory was designed in its original form to be administered as a questionnaire where the subject was asked which hand he uses to perform certain tasks, such as "throw a ball," "write your name," and "hammer a nail." However, we have modified the inventory so that the subject performs each task in front of the examiner while the examiner notes the hand used by the subject to perform the task. We presumed that having

the subjects actually perform the tasks would result in a more accurate representation of their handedness especially for the younger children. Based on the subject's performance on all the tasks, a quantitative handedness score was calculated. Scores ranged between +1 and -1, where a score of +1 indicated right hand dominance while a score of -1 indicated left hand dominance. It is a well-established finding in the literature that hand dominance is linked to cerebral lateralization for language and planar asymmetry.

Magnetic Resonance Imaging Scan Protocol

Two scan sequences were performed in a Siemens 1.0 Tesla Magnetom using a quadrature head coil: (1) a gradient echo volumetric acquisition "Turboflash" MP Rage sequence (Mugler and Brookman, 1990; TR = 10 ms, TE = 4 ms, FA = 10 degrees, 1 acquisition, 25.5 cm field of view, matrix = 130 x 256, 4.1 min) that is reconstructed into a gapless series of 128 1.25 mm thick images in the sagittal plane; (2) a traditional axial scan of 5 mm T2 and spin density weighted images separated by 2.5 mm gaps (time = 8 minutes). The second scan was read by a neuroradiologist to rule out pathology. The high resolution of the images provided by the gradient echo techniques made it possible to use an anatomically based measurement strategy.

Transfer of Images

The scans were archived on 12 inch optical disks at the scanner and then transferred to an optical disk series at a central "jukebox." From the jukebox, the scans were transferred to the hard disk of a Sun workstation in the Image Processing Laboratory (IPLAB) by fiberoptics network. In the IPLAB, each scan was assigned a blind identification number from a randomly generated list. Programs written in PV-

Wave (a programming language designed for handling large arrays from Visual Numerics, Inc., Boulder, CO) stripped the headers, reduced the data from 16 to 8 bits per pixel, and placed the images into a single file labeled with the blind number. This file contains all the sagittal images on which any cerebral cortex can be recognized (about 10,065,543 byte images and 6 MB per file). The midline section was identified as the section containing mammillary bodies, optic recess, infundibulum, anterior commissure, posterior commissure, and the greatest extent of the third ventricle. The width of each hemisphere was then calculated by subtracting the midline section number from the last cortical section on each side and multiplying by the section thickness (1.25 mm). Since there were no gaps in the volumetric data set from the gradient echo scan, the images could be reconstructed into any plane. The 1.25 mm thick sagittal images were used to measure the planum temporale. This thickness was determined to be appropriate because planum size does not vary much from medial to lateral. Sagittal images were reconstructed into 1 mm thick sagittal sections to measure pars triangularis and into 1 mm thick coronal sections to measure the superior temporal gyrus. Because pars triangularis and the superior temporal gyrus are more sensitive to head tilt and the size of these structures varies in position in plane, the sections were reformatted to correct for head tilt before measuring. Each image series was archived on a 5.5 inch 625 MB read/write optical disk.

Standardization Procedure

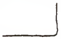
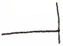
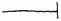
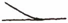
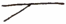
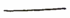
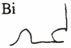
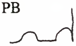
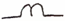
In order to insure that comparable images were examined in each brain the Talairach proportional grid method (Talairach and Tournoux, 1988) was used. This procedure involves dividing each hemisphere into four sagittal slabs of equal width by dividing the hemisphere width by four. The width of one of these slabs was defined as a standard unit (stu). This system is very useful for locating structures along the medial-lateral axis however, it is much less reliable for structures in the anterior-posterior and dorsal-ventral planes. Therefore, for this study, programs written in PV-Wave were used to convert the section numbers to this coordinate system for measurements made in the sagittal plane but real metric (mm) measurements were used for calculating distances in the coronal plane.

Structures to be Assessed

Qualitative Analysis

A 10-type classification system developed by C.M. Leonard and Robins (unpublished) was used to describe the posterior region of the sylvian fissure. Table 2-3 shows the classification system used. A program written in PV-Wave brought up 8 sagittal sections at half unit intervals between 2.25 and 3.00 stu's for each hemisphere. All sections in each hemisphere were analyzed individually for each fissure type. One point was awarded for each of the 8 sections containing a particular type of fissure. Therefore, for each hemisphere, a point score between 0 and 8 was awarded for each of the 10 classification types. For example, for a subject's left hemisphere, 3 points would be awarded for the "T" type fissure if this fissure was observed on 3 of the 8 sagittal sections, 5 points would be awarded for the "M" type of fissure if this type of fissure was observed on five of the 8 sections, and so on. For statistical analysis, each classification subtype was analyzed individually and in groups of normal and anomalous fissure types. Classification types "L," "T," "TA," and "S" were considered to be normal sylvian fissure configurations and classification types "F," "H," "V," and "M"

Table 2-3. Sylvian Fissure Classification (Leonard and Robins, unpublished).

L 	Planum flat PAR straight and angled approximately 90 degrees No trace of PDR ;Planum approximately twice as long as PAR
TA 	PAR at least twice the length of PDR; PDR perpendicular to PHR; Planum and PAR comparable in size; Planum continuous with Heschl's sulcus
T 	Planum long and flat PAR and PDR short, straight and equal
S 	At least two possible origins of PAR; Sharp angles between PHR and PAR; Possible small PDR
F 	PDR direct continuation of planum; PDR long and wavy; No incontrovertible PAR; PHR long and wavy
V 	PAR rises behind Heschl's gyrus; PAR long and bumpy; PAR bulges anteriorly; No or very short planum
M 	Anterior STS merges with PHR at or near Heschl's sulcus; Posteriorly two possible plana both originating from PHR; Posteriorly STS merges with PHR, one clear H-planum
H 	No PAR PHR long and irregular
Bi 	Bump directed anteriorly in inferior PAR confuses interpretation of L or TA; slight bulge directed forward confuses interpretation of L or TA.
PB 	Bump at posterior end of planum temporal; PAR and PDR form posterior side on bump.
MH 	Two Heschl's gyri.

Note: PAR (posterior ascending ramus); PDR (posterior descending ramus); PHR (posterior horizontal ramus); STS (superior temporal sulcus); H-planum (horizontal planum), MH (multiple Heschl's gyri)

were considered to be anomalous sylvian fissure configurations. Fissure Types "BI" and "PB" were analyzed individually because these types identify bumps on the posterior temporal bank and the inferior parietal bank of the planum respectively and do not describe the shape of the entire sylvian fissure. This decision was based on results of previous dyslexia studies of control children and adults (C.M. Leonard et al., 1993; C.M. Leonard et al., in press).

Multiple Heschl's gyri were also analyzed using this same method. Figures 2-1 and 2-2 provide examples of this classification system.

Quantitative Analysis

Width measurements for the left and right hemispheres and the area of the midsagittal section and the corpus callosum were made. Additionally, the length of the entire brain, from the anterior edge to the posterior edge, was measured. All gross brain measurements were obtained from the midsagittal section of each brain. Additionally, the surface area of the temporal and parietal banks of the planum temporale, pars triangularis and the superior temporal gyrus were measured. Measurements for each structure were made where the structure in question was the largest and most clearly defined. The planum temporale was measured from sagittal slices between 2.75 and 3.25 stu's and pars triangularis was measured from sagittal slices between 2.25 and 3.00 stu's. The anterior superior temporal gyrus was measured from coronal slices between 5 mm anterior and 5 mm posterior to the anterior commissure.

The hemispheric asymmetry of each structure was calculated by using a formula for the coefficient of asymmetry $(L - R)/ ((L + R) \times .5)$, 0.00 indicating symmetry, a positive number indicating leftward asymmetry and a negative number indicating

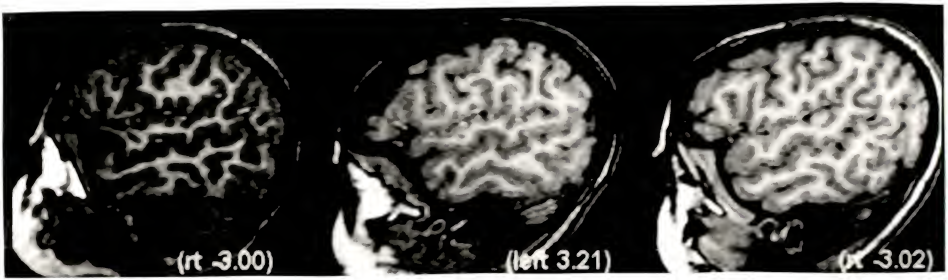


Figure 2-1. Examples of Sylvian Fissure Types: "L" fissure (left); "H" fissure (middle); "V" fissure (right).

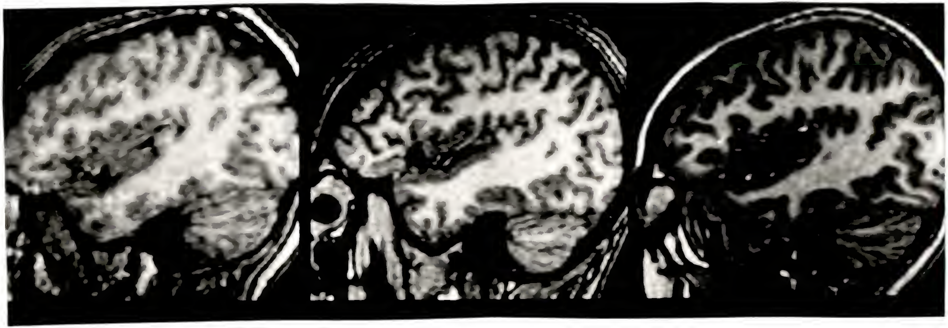


Figure 2-2. Heschl's Gyrus Classification Scheme: Example of a single Heschl's gyrus (left); common stem Heschl's gyrus (middle); multiple Heschl's gyri (right).

rightward asymmetry. The advantage of using an average length is that a standard deviation can be calculated allowing the determination of the probability of asymmetry for an individual brain, rather than use of an arbitrary criterion.

Measurement Technique

Surfaces were measured by manual tracing with a mouse-operated cursor on the image displayed on the Sun Workstation monitor at 4X magnification. The measurement technique used was adapted from Zilles, Armstrong, Schleicher and Kretschmann (1988). Cross-sectional areas of gyri were measured by tracing around the edge of the gyrus and connecting the most inferior points on either side. A program written in PV-Wave calculates each segment length when one cursor button is depressed and continually increments the surface distance of a structure until depression of another cursor button signals that the measurement is completed. A report page containing facsimiles of images and tracings of the first, middle, and last sections measured for each structure together with graphs of the length as a function of position were printed out on a laser printer, while the actual values, means, standard deviations, and average asymmetries were stored in a data file that was transferred to a computer and imported into a spreadsheet. Examples of the printouts from the PV-Wave programs used to measure the planum, pars triangularis and the superior temporal gyrus are found in Appendices A, B, and C.

Reliability

Interrater reliability was calculated for each structure measured. Two experimenters blind to subject identification independently measured each structure. When more than 10% disagreement between the average values for two measurements occurred, the experimenters conferred and the measurements were redone. Measurements were made by the author and the committee member who developed the programs for measuring.

Analysis of Data

Repeated measure ANOVAs (PC-SAS) with the Bonferroni correction were performed to examine the significance of differences between the groups. Multiple regressions and Pearson Correlations were used to examine the relationship between behavioral and structural variables.

CHAPTER 3
RESULTS

The purpose of this study was to use quantitative and qualitative methods to compare regions of the sylvian fissure in children with specific language impairment (SLI) and children with normal language skills. The goal of this study was to determine if children with deficient language abilities have anomalous morphology in the areas of the brain known to subserve language. Eleven children with SLI (males, 8; females, 3; age range 5.8 - 13.0 years) and 19 control children (males, 14; females, 5; age range 5.6 - 11.11 years) participated in this study. All subjects received a behavioral assessment that included tests of language, reading, nonverbal intelligence and handedness and a magnetic resonance imaging (MRI) scan of the brain. Quantitative measurements were obtained by measuring the length of the planum temporale, pars triangularis and the superior temporal gyrus. Qualitative data were obtained by classifying the shape of the posterior region of the sylvian fissure and Heschl's gyrus. Gross measurements of the widths of the hemispheres and volume of the corpus callosum were also made and analyzed for group differences.

Statistical Analyses

The means procedure from PC-SAS was used to examine the probability that group mean interhemispheric and intrahemispheric coefficients of asymmetry were significantly different from 0.00 (symmetry). Separate repeated-measures analyses of variance were used to examine the main effects on the variables subject group, sex and hemisphere side at the .05 level of significance. The Pearson correlation procedure was used to correlate behavioral data with brain morphology data.

Behavioral Analyses: Neurolinguistic, Cognitive and Reading Measures

The SLI children and the control children did not differ significantly on age and quantitative handedness. Table 3-1 shows results from repeated measures analyses of variance for control and SLI children on the neurolinguistic, cognitive and reading measures. The derived p-values for the behavioral measures listed in Table 3-1 that are equal to or less than the set .05 level of significance indicate that the means for the control and the SLI children were significantly different. Table 3-2 provides the mean behavioral data for the control and SLI children. Means for all neurolinguistic measures for the SLI children were significantly different from the means for the control children, with the control children demonstrating significantly greater mean scores than the SLI children on all neurolinguistic measures. While most of the SLI children demonstrated a relative strength with expressive vocabulary (EV), relative weaknesses were observed for syntactical/morphological knowledge (GC) and auditory memory (RS and OD). While the mean TONI scores for both groups were within the normal range, the mean TONI scores were significantly different for the SLI children and the control children ($F_{1,27} = 7.36$, $p = .01$). The SLI children had a mean TONI score of 92 while the control children had a mean TONI score of 102 (see Methods for discussion).

Reading ability for the two groups was also different. Word Identification subtest scores ($F_{1,27} = 12.76$, $p = .001$) and the Passage Comprehension subtest scores ($F_{1,26} = 23.52$, $p = .0001$) for the SLIs were significantly different from the controls with the control children's mean standard scores greater than the SLI children's mean

Table 3-1. Repeated Measures Analyses of Variance Results on Neurolinguistic Measures for Controls and Children with Specific Language Impairment (SLI).

Measure	Statistic
Language	
Grammatic comprehension (GC)	$F_{1,27}$ = 23.05, p = .0001*
Recalling sentences (RS)	$F_{1,27}$ = 37.94, p = .0001*
Formulated sentences (FS)	$F_{1,27}$ = 13.66, p = .001*
Oral directions (OD)	$F_{1,27}$ = 19.64, p = .0001*
Characteristics (CH)	$F_{1,10}$ = 7.06, p = .02*
Sentence structure (SS)	$F_{1,26}$ = 16.51, p = .0004*
Word associations (WA)	$F_{1,9}$ = 9.33, p = .01*
Expressive vocabulary (EV)	$F_{1,25}$ = 20.49, p = .0001*
Reading	
Passage comprehension (PC)	$F_{1,26}$ = 23.52, p = .0001*
Word attack (RA)	$F_{1,27}$ = 3.61, p = .0682
Word identification (WI)	$F_{1,26}$ = 12.76, p = .0014*
Phonemic awareness (LA)	$F_{1,27}$ = 3.97, p = .0565
Nonverbal IQ	
Test of Nonverbal Intelligence (TO)	$F_{1,27}$ = 7.36, p = .0115*

*mean scores significantly different for the SLI and control chidren at .05 level of significance

Table 3-2. Mean Scores for Controls and Children with Specific Language Impairment (SLI) on all Behavioral Measures.

Test	SLI Group	Control Group
TOLD-P2 and TOLD-1		
Grammatic comprehension (GC)	5.70 ± 2.91	10.26 ± 2.16
Characteristics (CH)	6.33 ± 1.15	9.33 ± 1.80
CELF-R		
Recalling sentences (RS)	4.80 ± 2.25	11.11 ± 2.79
Formulated sentences (FS)	4.50 ± 2.51	8.42 ± 2.81
Oral directions (OD)	5.00 ± 2.16	9.26 ± 2.60
Sentence structure (SS)	7.33 ± 4.06	12.26 ± 2.38
Word associations (WA)	6.25 ± 2.43	11.00 ± 1.73
EOWPVT-R		
Expressive vocabulary (EV)	88.88 ± 24.11	119.9 ± 11.9
WRMT-R		
Passage comprehension (PC)	75.67 ± 17.68	102.2 ± 11.2
Word attack (RA)	87.80 ± 18.43	98.95 ± 13.0
Word identification (WI)	79.89 ± 25.05	103.8 ± 10.9
Lindamood Auditory Conceptualization Test (LA)	46.80 ± 32.83	68.47 ± 25.0
Test of Nonverbal Intelligence (TO)	92 ± 11.1	102 ± 8.9

TOLD-P2 = Test of Language Development-Primary 2;
TOLD-I = Test of Language Development-Intermediate;
CELF-R = Clinical Evaluation of Language Fundamentals-Revised;
EOWPVT-R = Expressive One Word Picture Vocabulary Test - Revised;
WRMT-R = Woodcock Reading Mastery Test - Revised;
Values are mean ± SD.

Note: Mean standard scores reported for TOLD and CELF-R are based on a mean of 10 and a standard deviation of 3. Mean standard scores reported for EOWPVT-R and WRMT-R are based on a mean of 100 and a standard deviation of 15. Mean raw data reported for the LACT. Grammatical comprehension subtests of the TOLD-P2 and TOLD-I were collapsed into one category.

standard scores. The SLI children demonstrated somewhat impaired phonemic awareness skills compared with the control children with p-values approaching the level of significance for the two groups on the LACT ($F_{1,27} = 3.99$, $p = .06$) and Word Attack subtest ($F_{1,27} = 3.61$, $p = .07$). The LACT mean standard scores for the control children was 68.47, but only 46.80 for the SLI children. The Word Attack mean standard scores for the control children was 98.95, but only 87.80 for the SLI children.

Comparative Analyses of Brain Structures and Correlational Findings Between Structures and Behavioral Measures

Pars Triangularis

The left pars triangularis was significantly smaller in the SLI group than in the control group ($F_{1,28} = 7.52$, $p = .01$). The length of pars triangularis in the left hemisphere was 3.2 cm for the control children, but only 2.4 cm for the children with SLI. Table 3-3 provides the mean data for pars triangularis for the control and SLI children. No significant subject group differences were observed for the right pars triangularis. Individual examination of the data indicate that the direction of asymmetry for the planum and pars triangularis was the same for the SLI children (the six children with rightward asymmetry of the planum also had rightward asymmetry of pars triangularis and the 5 children with leftward asymmetry of the planum also had leftward asymmetry of pars triangularis). This relationship was not found in the control children.

Moderate positive correlations were observed between quantitative handedness and the right pars triangularis ($r = .44$, $p < .05$) and between Grammatic Comprehension and left pars triangularis ($r = .40$, $p < .05$), suggesting the length of pars triangularis on the right side is associated with handedness and the length of pars triangularis on the left side is associated with grammatical knowledge. A moderate negative correlation was noted between age and right pars triangularis ($r = -.47$, $p < .05$), suggesting that the length of the right pars triangularis decreases with age.

Table 3-3. Mean Length (in cm) of Pars Triangularis in Controls and Children with Specific Language Impairment (SLI).

	Control Group (n = 19)	SLI Group (n = 11)
Left	3.2 ± 0.8*	2.4 ± 0.7*
Right	2.8 ± 0.8	2.6 ± 0.7
COA	0.14 ± 0.5	-0.09 ± 0.3

COA = Coefficient of asymmetry: (L-R) / [(L+R) / .5]
* Means of left pars triangularis significantly different for controls and SLIs; p =.01.
The mean for each group represents an average of eight to ten sections through the pars triangularis in each individual.
Values are mean ± SD.

Planum Temporale

Total Planar Measurements. Total planar asymmetry for the two groups was significantly different ($F_{1,28} = 5.48$, $p = .03$). When the mean total values of the temporal and parietal banks were summed to give total planum values for the left and right hemispheres, the control children demonstrated slight mean leftward asymmetry (L = 4.5 cm, R = 4.1 cm) yielding an asymmetry coefficient of .09, while the SLI children demonstrated slight rightward asymmetry (L = 3.8 cm, R = 4.3 cm) yielding an asymmetry coefficient of -.16. While .09 and -.16 are significantly different from each other, they were not significantly different from 0, indicating symmetrical total planar measurements for both groups. Planum data for the control and SLI children can be found in Table 3-4.

Table 3-4. Mean Length (in cm) of the Temporal and Parietal Banks of the Planum and Interhemispheric Coefficients of Asymmetry in Controls and Children with Specific Language Impairment (SLI).*

	Control Group	SLI Group
Temporal Bank (T)		
Left	3.2 ± 0.7	2.6 ± 1.2
Right	2.3 ± 0.8	2.2 ± 1.2
Inter COA (%)	33 ± 32	20 ± 65
Parietal Bank (P)		
Left	1.3 ± 0.8	1.2 ± 0.6
Right	1.8 ± 0.6	2.1 ± 0.9
Inter COA (T)	-40 ± 71	-52 ± 58
Total Planum		
Left	4.5 ± 0.8	3.8 ± 0.9
Right	4.1 ± 0.7	4.3 ± 1.05
Total Asymmetry	0.09 ± 0.38	-0.16 ± 0.21*

Inter COA = interhemispheric coefficient of asymmetry: (L-R) / [(L+R) / .5].

* p < .05

The mean for each group represents an average of six to eight sections through the planum in each individual.

Values are mean ± SD.

Temporal and Parietal Bank Measurements. Interhemispheric asymmetry of the temporal bank and parietal bank were not significantly different for the two subject groups. Both groups demonstrated mean leftward asymmetry of the temporal bank and mean rightward asymmetry of the parietal bank. For the control children, 16/19 (84%) had leftward asymmetry of the temporal bank, 2/19 (11%) had rightward asymmetry of the temporal bank and in one (5%) control child the left and right temporal banks were equal in length. For the SLIs, 6/11 (55%) had leftward asymmetry of the temporal banks, 4/11 (36%) had rightward asymmetry of the temporal bank and in one SLI subject (9%) the left and right temporal banks were equal in length. Parietal bank measurements for the control children revealed 6/19 (32%) children with leftward asymmetry, 9/19

(48%) had rightward asymmetry and 4/19 (21%) had symmetry of the left and right parietal banks. For the SLI children, 9/11 (82%) had rightward asymmetry of the parietal bank and 2/11 (18%) had leftward asymmetry of the parietal bank.

All subjects, with the exception of two control children (90%) and two SLIs (82%), had larger temporal than parietal banks in the left hemisphere. In the right hemisphere the inverse was observed; 11/19 (58%) controls and 7/11 (64%) SLIs had larger temporal than parietal banks.

Moderate positive correlations were observed between total planar asymmetry and LACT scores ($r = .50$, $p < .02$), Passage Comprehension scores ($r = .44$, $p < .02$), and Grammatic Comprehension scores ($r = .37$, $p < .05$), suggesting that increased total planar asymmetry was associated with better phonemic awareness, reading comprehension and knowledge of grammatical forms. Moderate positive correlations between Word Attack scores and the left parietal bank ($r = .44$, $p < .02$) and parietal bank asymmetry ($r = .46$, $p < .01$) were also noted. All together, these results suggest that phonemic awareness is associated specifically with the length of the left parietal bank. No significant correlations were observed between the planum and handedness scores.

Superior Temporal Gyrus

Mean volume of the left and right anterior superior temporal gyrus did not differ significantly between subject group and hemisphere side. Both groups demonstrated symmetry of the anterior superior temporal gyrus. No significant correlations were found between the anterior superior temporal gyrus and the behavioral data or handedness score. Table 3-5 shows the mean length data of the anterior superior temporal gyrus.

Table 3-5. Mean Length (in cm) of the Anterior Superior Temporal Gyrus (STG) for Controls and for Children with Specific Language Impairment (SLI).

	Control Group (n = 19)	SLI Group (n = 10)*
Left	3.05 ± 0.8	2.91 ± 0.6
Right	3.14 ± 0.6	2.83 ± 0.7
Asymmetry	-0.04 ± 0.2	0.03 ± 0.8

* For one child in the SLI group, the STG could not be measured due to metal artifacts of the MRI scan.

Gross Brain Measurements

Both the left hemisphere ($F_{3,26} = 7.22$, $p = .01$) and the right hemisphere ($F_{3,26} = 5.83$, $p = .02$) were significantly larger for the males than for the females, with the control children having a significantly larger right hemisphere than the SLI children ($F_{3,26} = 4.44$, $p = .05$). The area of the midsagittal section was significantly greater in the males than in the females ($F_{3,26} = 7.00$, $p = .01$). The size of the corpus callosum and the length of the brain were not significantly different between group or sex. Mean gross brain measurements can be found in Table 3-6.

Table 3-6. Mean Gross Brain Measurements (in cm) for the Left (LH) and Right (RH) Hemispheres, Midsagittal Section (MS), Length of the Brain (LEN), and the Corpus Callosum (CC).

	Subjects	Controls	Males	Females
LH	6.40	6.45	6.51	6.23*
RH	6.30	6.52*	6.51	6.24*
MS	150.10	152.18	154.26	143.48*
LEN	16.41	16.79	16.82	16.17
CC	5.82	6.23	6.14	5.93

* $p < .05$.

Comparative Analyses for the Sylvian Fissure and Correlational Findings between the Sylvian Fissure and Behavioral Measures

Sylvian Fissure

The shape of the posterior sylvian fissure was analyzed using a 10 category classification scheme. For statistical analysis, each classification category was analyzed individually and in groups of normal and anomalous fissure types. Classification types "L," "T," "TA," and "S" were considered to be normal sylvian fissure configurations and classification types "F," "H," "V," and "M" were considered to be anomalous sylvian fissure configurations. This decision was based on the results of previous dyslexia studies on control children and adults (C.M. Leonard et al., 1993; C.M. Leonard et al., in press). Results of the correlational analyses validate this classification system; negative correlations were found between anomalous fissures and language scores and positive correlations were found between normal fissures and language scores. Thus, the presence of the normal fissures was associated with higher language scores while the presence of the anomalous fissures was associated with lower language scores supporting the assignment of fissure types to "normal" or "anomalous" categories. Types "PB" and "BI" were analyzed separately as these classifications identify bumps in the posterior temporal bank of the planum and the inferior parietal bank of the planum respectively. These two classifications do not describe the shape of the entire sylvian fissure and data do not exist concerning their frequency in the left and right hemisphere.

Anomalous Fissures

The frequency of anomalous sylvian fissure types was significantly greater in the SLI group than in the control group ($F_{3,56} = 7.51$, $p = .001$). Table 3-7 provides the

Table 3-7. Mean Frequency of Sylvian Fissure Classification Types and Multiple Heschl's Gyri for Controls and for Children with Specific Language Impairment (SLI).

	Control Group	SLI Group
LEFT HEMISPHERE		
Anomalous Fissures	5.52 ± 5.99	9.36 ± 7.90
"F"	1.00 ± 1.63	3.27 ± 3.35*
"M"	0.58 ± 1.07	1.00 ± 2.19*
"V"	1.84 ± 3.27	1.27 ± 2.69
"H"	0.84 ± 1.83	1.91 ± 3.18†
Normal Fissures	6.58 ± 4.50	4.73 ± 3.64
"L"	0.84 ± 1.21	0.82 ± 1.25†
"T"	1.47 ± 1.81	1.36 ± 1.50†
"TA"	2.68 ± 2.56	2.09 ± 2.55†
"S"	1.58 ± 2.73	0.45 ± 1.04
Posterior Temporal Bumps		
"PB"	3.21 ± 2.87	2.72 ± 3.49†
"BI"	2.68 ± 2.56	1.00 ± 1.73
Multiple Heschl's Gyri	1.26 ± 2.25	1.90 ± 2.80
RIGHT HEMISPHERE		
Anomalous Fissures	6.47 ± 3.78	12.36 ± 7.75
"F"	1.21 ± 2.15	2.45 ± 3.05
"M"	0.11 ± 0.46	1.45 ± 1.69
"V"	2.21 ± 3.24	5.09 ± 4.04*†
"H"	0.16 ± 0.69	0.45 ± 1.04
Normal Fissures	6.47 ± 3.78	4.09 ± 4.72
"L"	3.21 ± 2.64	1.82 ± 3.19
"T"	0.32 ± 0.95	0.18 ± 0.60
"TA"	0.84 ± 1.86	1.09 ± 2.47
"S"	2.11 ± 2.79	1.00 ± 2.24
Posterior Temporal Bumps		
"PB"	0.42 ± 1.83	0.72 ± 2.41
"BI"	2.26 ± 2.78	3.09 ± 2.47
Multiple Heschl's Gyri	2.57 ± 2.89	2.90 ± 2.50

* Indicates a significant difference of occurrence between SLI and control children at .05 level of significance; † indicates a significant difference of occurrence between the left and right hemisphere at .05 level of significance.
Values are mean ± SD.

frequency data for the sylvian fissure types for the control and SLI children. In the control group, the mean for anomalous fissures was 5.52 in the left hemisphere and 6.47 in the right hemisphere. In the SLI group, the mean for anomalous fissures was 9.36 in the left hemisphere and was 12.36 in the right hemisphere. Therefore, the mean frequency of anomalous fissures across both left and right hemispheres in the control group was 5.9 [(5.52 + 6.47) / 2], while in the SLI group it was 10.86 [(9.36 + 12.36) / 2]. Types "F" ($F_{3,56} = 7.18$, $p = .001$) and "M" ($F_{3,56} = 6.04$, $p = .02$) occurred significantly more frequently in the SLI children than in the control children, while type "V" occurred significantly more often on the right in the SLI group ($F_{3,56} = 3.76$, $p = .05$). Type "H" showed an effect for side of hemisphere; it occurred significantly more often in the left hemisphere than in the right hemisphere ($F_{3,56} = 4.34$, $p = .04$).

Normal Fissures

The frequency of the normal fissure types did not differ significantly between groups, however effects were observed for side of hemisphere. Types "T" ($F_{3.26} = 11.32$, $p = .001$) and "TA" ($F_{3,56} = 6.44$, $p = .01$) occurred significantly more frequently in the left hemisphere than in the right, while Type "L" ($F_{3,26} = 10.88$, $p = .002$) occurred significantly more frequently in the right hemisphere. The occurrence of type "S" did not differ significantly between subject groups or hemisphere side. Additionally, a significant side effect was noted for fissure type "PB." It occurred more often in the left hemisphere than in the right.

Correlations of Fissure Types and Behavioral Measures

Moderate correlations were observed between fissure types and behavioral measures, with correlation coefficients ranging between -0.63 and +0.66. Correlational data for the left and right hemispheres are found in Table 3-8. In the left hemisphere, the most

Table 3-8. Significant Correlational Data for Sylvian Fissure Types and Behavioral Data for the Left and Right Hemispheres.

Sylvian Fissure Type	Behavioral Subtest	Correlational Statistic (r)
Left Hemisphere		
BI	RS	.47
	FS	.49
	OD	.42
	WI	.47
PB	EV	.41
T	CH	.58
TA	FS	.51
V	WA	-.63
F	TO	-.48
Right Hemisphere		
M	CH	-.58
	RS	-.54
	FS	-.49
	OD	-.55
	PC	-.49
	WA	-.41
	WI	-.49
T	OD	.53
	WA	.66
BI	CH	-.66
PB	TO	-.42

RS = Recalling Sentences; FS = Formulated Sentences; OD = Oral Directions; WI = Word Identification; EV = Expressive Vocabulary; CH = Characteristics; WA = Word Association; TO = Test of Nonverbal Intelligence; PC = Passage Comprehension; $p \leq .05$

notable correlations were a strong negative correlation between type "V" fissure and Word Attack scores ($r = -0.63$, $p < .05$) and a positive correlation between fissure type "T" and Characteristics score ($r = .58$, $p < .05$). Fissure type "BI" correlated positively with Recalling Sentences score ($r = .47$, $p = .01$), Formulated Sentences score ($r = .49$, $p < .01$), Oral Directions score ($r = .42$, $p < .05$) and Word Identification score ($r = .47$, $p < .01$). Also in the left hemisphere, fissure type "TA" correlated positively with Formulated Sentences scores ($r = .51$, $p = .005$), fissure type "F" correlated negatively with TONI scores ($r = -.48$, $p = .009$), and fissure type "PB" correlated positively with EOWPVT-R ($r = .42$, $p = .03$) and age ($r = .44$, $p = .01$).

In the right hemisphere, a high moderate negative correlation was observed between fissure type "BI" and Characteristics score ($r = -0.66$, $p < .05$) and high moderate positive correlations were observed between fissure type "T" and the Word Attack scores ($r = .66$, $p < .05$) and Oral Directions scores ($r=.53$, $p = .003$). Also on the right, fissure type "M" correlated negatively with Characteristics score ($r = -.58$, $p < .05$), Recalling Sentences score ($r = -.54$, $p < .005$), Formulated Sentences score ($r = -.49$, $p < .01$), Oral Directions score ($r = -.55$, $p < .005$), Passage Comprehension score ($r = -.49$, $p < .01$), Word Attack score ($r = -.41$, $p < .05$) and Word Identification score ($r = -.49$, $p < .01$). Additionally, moderate negative correlations were noted between fissure type "V" and Word Attack scores ($r = -.35$, $p = .05$) and Word Identification scores ($r = -.40$, $p = .03$). Finally, fissure type "L" had a moderate positive correlation with Word Attack scores ($r = .37$, $p = .05$) and fissure type "PB" had a moderate negative correlation with TONI scores ($r = -.42$, $p = .02$).

Heschl's Gyrus

The frequency of multiple Heschl's gyri did not significantly differ between subject group or side of hemisphere. Table 3-7 provides a summary of the mean occurrence of multiple Heschl's in the SLI children and control children and for the left and right hemisphere. A high moderate negative correlation was observed between multiple Heschl's gyri and Characteristics score (r = -.57, p = .05). No significant correlation was observed between multiple Heschl's gyrus and handedness score.

Summary of Findings

The results of this study confirm previous findings indicating that children with impaired language abilities have anomalous morphology in the areas of the brain that subserve language. There were seven major findings in this study: (1) The left pars triangularis was significantly smaller in the SLI group (rightward asymmetry) than in the control group, but no significant differences for subject group or side of hemisphere were observed for the right pars triangularis; (2) For the planum temporale, both subject groups demonstrated a longer temporal bank in the left hemisphere than in the right (leftward asymmetry) and a longer parietal bank in the right hemisphere than in the left (rightward asymmetry), however total planar asymmetry for the two subject groups was significantly different with the control children demonstrating slight leftward asymmetry, and the SLI children demonstrating a slight rightward asymmetry; (3) The frequency of anomalous fissures (Types F, M, V, and H) was significantly greater for the SLI children than for the control children; (4) Asymmetry findings for the planum temporale, pars triangularis and sylvian fissure were related to language ability; (5) The SLI children had significantly smaller right hemisphere widths than the control children; however, left hemisphere widths for the two groups were similar; (6) The frequency of multiple Heschl's gyri did not differ significantly for subject group or side of hemisphere; and, (7) The mean volume of the left and right superior temporal gyrus did not differ significantly between subject group or hemisphere side. A summary of the brain morphology asymmetry data for the SLI and control children can be found in Appendices D and E, respectively. A summary of the sylvian fissure classification findings for the SLI and control children can be found in Appendices F and G, respectively.

CHAPTER 4
DISCUSSION

The purpose of this study was to use quantitative and qualitative methods to compare regions of the sylvian fissure in children with specific language impairment (SLI) and in children with normal language skills to determine if children with deficient language abilities have anomalous morphology in the areas of the brain known to subserve language. The neuroanatomical results of this study demonstrate that children with language impairment have atypical asymmetry of the perisylvian structures devoted to language functioning. The planum temporale, pars triangularis and the posterior region of the sylvian fissure were found to be significantly different in children with SLI when compared with children without language impairment. Furthermore, anomalous morphology of these language areas of the brain correlated with depressed language ability. These findings provide support for the hypothesis that language impairment is a consequence of an underlying neurobiological defect in the areas of the brain known to subserve language functions.

Behavioral Battery

The two groups of children were matched for age, sex and handedness. Neurolinguistic test measures confirmed appropriate group assignment, as the SLI children demonstrated significantly depressed scores on all language measures in comparison to the normal controls. Reading comprehension and sight word reading were also significantly impaired in the SLI group compared with the control children. While only approximating statistical significance, the SLI children demonstrated a 20 point deficit in mean LACT score compared with the control children. Phonemic awareness is the knowledge of the sound structure of one's language and impaired phonemic awareness is a primary symptom in developmental dyslexia. These findings suggest that the children with SLI who demonstrate impaired phonemic awareness share this behavioral characteristic with children with dyslexia and further suggest that the neurobiological basis of both disorders may be rooted in dysfunctions specific to the language areas of the brain.

The mean nonverbal intelligence scores for both groups of children were within the normal range, however the SLI children scored on average 10 points below the control children. Nonverbal discrepancies such as these have also been reported by Hynd et al. (1990) and Jernigan et al. (1991) in their studies of children with developmental language disorders. A possible reason for these IQ discrepancies could be inherent in the nonverbal task itself. In the administration of the TONI, there is no verbal communication. The child is provided with pantomimed instructions that demonstrate to the child the appropriate response of pointing to the correct response from a choice of 5 or 6 that completes the puzzle. Although the TONI is intended to be a language-free measure of cognitive ability, it is quite probable that children use linguistic strategies in approaching this nonlinguistic task. For example, when shown a test stimulus picture, the child may analyze the picture and internally describe the characteristics of the picture in order to figure out the logical missing piece from the choices (e.g., the child may describe the picture "in his head" by saying, "this circle has one square on the left, this circle has one square on the right, so this square should have...). Therefore, although the response mode of this test is nonlinguistic, it cannot be stated with any degree of certainty that it is a language-free measure of intellectual functioning. The issue of IQ is further complicated by the fact that as one gets older the metalinguistic skill of using established language to acquire new language is enhanced; therefore, impaired language skills may hinder the acquisition of new knowledge. As noted earlier, researchers have observed a decrease in IQ with age. This issue is similar to the Matthew effect discussed earlier.

Pars Triangularis

The SLI children in this study demonstrated atypical asymmetry of pars triangularis compared with the control children. In the left hemisphere, the SLI children had a significantly smaller pars triangularis than the control children, while in the right hemisphere the pars triangularis did not differ for the two groups. Individual examination of the data indicate that the direction of asymmetry for the planum and pars triangularis was the same in the SLI children (the six SLI subjects with rightward asymmetry of the planum also had rightward asymmetry of pars triangularis and the five SLI subjects with leftward asymmetry of the planum also had leftward asymmetry of pars triangularis), but this relationship was not found in the control children. The finding of rightward asymmetry of pars triangularis in the language-impaired population contrasts with findings from studies of nonlanguage-impaired adults. Foundas et al. (1993; 1995) found leftward asymmetry of pars triangularis in studies of normal and epileptic adults. In contrast to the results of the current study, however, the controls in the Foundas et al. (1994) study demonstrated similar direction of asymmetry for the planum and pars triangularis. This discrepancy in results may be explained by the difference in ages of the subjects in the two studies, but more subjects would need to be examined before any conclusions can be drawn.

A moderate correlation was found between leftward asymmetry of pars triangularis and expressive syntactical/morphological ability. This knowledge was measured with a task that requires the manipulation of phonemic units that correspond to grammatical markers (Grammatic Completion subtest of TOLD). Pars triangularis makes up the core of Broca's area. A primary symptom exhibited by patients with lesions to Broca's area is agrammatic speech which is characterized by a reduction and simplification of grammatical forms (Albert, Goodglass, and Helm, 1981). Therefore, these findings are consistent with the literature on the function of Broca's area and suggest that developmental anomalies of pars triangularis might produce results similar to those stemming from acquired lesions to this area. Furthermore, these findings support a structure-function relationship between pars triangularis in Broca's area and language function. This relationshop has not been examined in the SLI population previously. In a positron emission tomography (PET) study of 10 healthy volunteers, Zatorre, Evans, Meyer, and Gjedde (1992) found evidence supporting the role of Broca's area in phonemic discrimination. The subjects in their study were instructed to press a key to indicate if pairs of consonant-vowel-consonant combinations end with the same consonant sound. The authors reported that the greatest increase in blood flow was observed in Broca's area and concluded that when making phonetic judgements, subjects must access an articulatory representation involving neural circuits that include Broca's area.

Planum Temporale

There has been considerable inconsistency in the methods used to measure the planum temporale across studies reported over the past several years. While some researchers combine the temporal and parietal banks in their measurement of the planum (Cohen et al., 1990; Galaburda, 1989; Hynd et al., 1990; Larson et al., 1990; Schultz et al., 1994); others measure the banks separately (C.M. Leonard et al., 1993; Rubens et al., 1976; Steinmetz et al., 1990; Witelson et al., 1992). Possible reasons for not distinguishing the temporal and parietal banks include an inability to visualize the individual banks because of MRI scan method limitations and difficulty in developing reliable procedures to identify and measure both banks. The distinction between the two banks is important because it is leftward asymmetry of the temporal bank (longer temporal bank on the left) that is associated with language localization.

In studies measuring the temporal and parietal banks in normal children and adults, C.M. Leonard et al. (1993; in press), Steinmetz et al. (1990), and Witelson et al. (1992) found the temporal bank to be longer in the left hemisphere and the parietal bank to be longer in the right hemisphere. Findings in this study corroborate previousl reports are critical to consider because leftward asymmetry may be obscured when both banks are included in the total planum measurement. Thus, planar measurements in this study were reported in two ways: (1) temporal and parietal bank measurements summed together to derive at a total planum length; and, (2) temporal and parietal bank measurements individually.

Comparison of Data to Studies Using Total Planar Measurements

The atypical total planar asymmetry (R > L or R = L) observed in the SLI children confirms the finding of Cohen et al. (1989), the only published study of the planum in a child with SLI. Other researchers have examined an entire perisylvian region containing the planum temporale in SLI children and have reported conflicting results. While Plante et al. (1991) found atypical perisylvian asymmetry in their group of SLI boys, Jernigan et al. (1991) did not.

Investigation of the planum temporale is more common in the dyslexic population and the finding in this study of atypical asymmetry in the SLI population is consistent with early findings in this literature. Galaburda (1989), Hynd et al. (1990), and Larson et al. (1990) found symmetry or reversed asymmetry of the total planum length in their studies of children and adults with dyslexia. C.M. Leonard et al. (1993) found symmetry of the total planum in their group of dyslexic adults, but planar symmetry was also found in their group of control subjects. In contrast, Schultz et al. (1994) found leftward asymmetry of the total planum in both the controls and the dyslexics. It should be pointed out, however, that there are two major problems with the methodology used by Schultz et al. (1994). Firstly, they measured the planum from coronal MRI sections, while visualization of the planum can be best accomplished with sagittal sections. Secondly, Schultz et al. (1994) reported that they could not reliably identify Heschl's gyrus, the anterior boundary of the planum, when measuring the planum. As a result, they defined the anterior boundary of the planum as the rostral-most section not containing the insula of Reil. Schultz et al. (1994) admit that this definition of the planum may exclude small anterior-lateral portions of the planum and might include anterior-medial aspects of Heschl's gyrus. These methodological problems may explain the discrepancy in their results with the results of this study and others.

Comparison of Data to Studies Using Separate Temporal and Parietal Banks

Both the SLI children and the control children had leftward asymmetry of the temporal bank and rightward asymmetry of the parietal bank. This finding is consistent with data from the C.M. Leonard et al. (1993) study of dyslexics. However, C.M. Leonard et al. (1993) reported finding exaggerated leftward asymmetry of the temporal bank due to a significant shift of right planar tissue from the temporal to parietal bank in the dyslexic group. Thus, asymmetry was due to a short right temporal bank in their group of dyslexic subjects. This was not the case in this study of SLI children. In the right hemisphere of the SLI children, the temporal and parietal banks were relatively equal in length, while in the left hemisphere the temporal bank was more than twice the length of the parietal bank but still considerably shorter than the temporal bank in the controls. These findings suggest that the primary morphological difference between the SLI children and the control children is a considerably shorter left temporal bank. These findings further suggest that atypical planar asymmetry due to a short left temporal bank may be a morphometric characteristic of severe oral language problems.

Relationships Between Planar Asymmetry and Language Functions

Reversed planar asymmetry due to a shorter left temporal bank most strongly correlated with phonemic awareness, reading comprehension and syntactical/morphological knowledge. The relationship between phonemic awareness and planar asymmetry is consistent with previous literature. Larson et al. (1990) reported that their dyslexic subjects with pure phonologic deficits had symmetrical plana. More recently, in a study by C.M. Leonard et al. (in press) of 40 normal children, they found that children with well-developed phonemic awareness had significantly greater leftward asymmetry of the temporal bank than their peers. Results of a PET study of men with dyslexia conducted by Rumsey, Andreason, Zametkin, Aquino, King, Hamburger, Pikus, Rapoport, and Cohen (1992) demonstrated a functional relationship between phonemic awareness and temporoparietal areas of the brain. They reported that the dyslexic men in their study failed to activate the same left temporoparietal regions as the control men during rhyme detection tasks and that this left temporoparietal dysfunction was demonstrated only when specific probes for phonemic awareness were used. The sections of the left temporoparietal region that showed the greatest difference in blood flow for the two groups of subjects were the parietal and middle temporal regions.

In the present study, total planar asymmetry was also associated with expressive syntactical/morphological knowledge. The task used to measure this knowledge involved manipulating phonemic units that correspond to grammatical markers. For example, the subject was required to provide the missing word in response to two sentences presented auditorily: "Mary likes to throw the ball. Yesterday she _____ the ball." Taken together, these results support the literature indicating the role of the planum temporale in the storage and retrieval of the phonemic units in language and suggests that anomalous asymmetry of the planum may be associated with impaired language abilities.

Superior Temporal Gyrus

Both the SLI children and the control children demonstrated symmetry of the anterior superior temporal gyrus. Studies of adults with schizophrenia report rightward asymmetry of the superior temporal gyrus while the controls demonstrate leftward asymmetry (Barta et al.,1990; Shenton et al., 1992; and Gautier et al., 1995). It appears from our data that our control children had larger anterior superior temporal gyri than the adult control subjects included in the Gautier et al. (1995) study suggesting that the volume of the anterior superior temporal gyrus may differentially decrease with age; while both hemispheres decrease in size with age, the right anterior superior temporal gyrus may shrink more than the corresponding gyrus in the left hemisphere. Longitudinal studies are necessary to test this hypothesis.

The volume of the anterior superior temporal gyrus did not correlate with language ability. This finding is especially interesting because anomalies were found in the planum and Heschl's gyrus, two structures that lie on the anterior superior temporal gyrus. Thus, findings from this study suggest that the anomalies associated with developmental language impairment in children are localized to specific structures located on the posterior superior temporal gyrus and not the anterior superior temporal gyrus. The superior temporal gyrus has not been examined in previous studies of children with developmental language disorders.

Gross Brain Measurements

Hemispheric width measurements of the brain revealed that the SLI children and control children in this study had similar left hemispheres, while the right hemispheres were different. The right hemispheres in the SLI children were significantly narrower than the corresponding hemispheres in the control children. When grouped by gender, both males and females had symmetrical hemispheric widths, while both hemispheres were significantly narrower in the females. Sex differences like these have been found in other studies. Giedd, Snell, Lange, Rajapakse, Kaysen, Vaituzis, Vauss, Hamburger, Kozuch and Rapoport (in press), in an MRI study of healthy males (n = 55) and healthy females (n = 50) between the ages of 4 - 18 years, found males to have significantly larger cerebral volumes than females. This difference remained significant after correction for height and weight. Giedd et al. (in press) also found that total cerebral volume did not change significantly across this age span. Schultz et al. (1994) and Filipek, Richelme, Kennedy and Caviness (1994) also reported similar sex differences in their studies of children and young adults.

Sylvian Fissure

The frequency of anomalous fissures was significantly greater in the SLI children than in the control children. In the left hemisphere, fissure types F and H (anomalous fissures with flat temporal segments and no vertical segments) and fissure type M (anomalous fissure where the superior temporal sulcus merges with the planum at or near Heschl's gyrus) occurred more often in the SLI children than in the control children. In the right hemisphere, fissure types F, H, and M also occurred more often in the SLI children along with type V (anomalous fissure where the temporal bank is absent or very short). Increased incidence of sylvian fissure anomalies was also found in a study by C.M. Leonard et al. (1993) in which they reported that 6 out of 9 dyslexic subjects had anomalous fissures, while only 2 of 12 control subjects had anomalous fissures. As in this study, the dyslexic subjects also exhibited flat temporal segments with little or no parietal segments in the left hemisphere. The shape of the sylvian fissure has not been analyzed in the SLI population previously.

Language skills appear to be related to the shape of the sylvian fissure. In the left hemisphere, the occurrence of fissure type V was related to poor word association skills. Word association tasks assess the storage and retrieval strategies for words. For example, the subject is asked by the examiner to name all the animals he/she can in 60 seconds. In fissure type V, the temporal bank of the planum, the part that receives information from Heschl's gyrus and is involved with the storage and retrieval of acoustic-phonemic patterns for words, is either absent or very short, indicating that the temporal bank of the planum may be associated with the storage and retrieval of words. In the right hemisphere, the existence of fissure type M, in which the superior temporal gyrus merges at or near Heschl's gyrus, was associated with poor auditory memory, expressive and receptive vocabulary and reading. Again, these findings suggest that sylvian fissure anomalies of the left and right hemispheres are associated with impaired language skills. Anomalies of the left hemisphere are expected to be associated with language impairment since this hemisphere has been identified as the dominant hemisphere for speech and language. However, relationships between anomalous configurations in the right sylvian fissure and language ability were also found and this finding is consistent with observations by C.M. Leonard et al. (1993) of anomalies in the right hemisphere in subjects with dyslexia.

The finding of right hemisphere anomalies in the perisylvian area of the SLI children in this study may be due to the brain's compensatory reorganization in response to behavioral deficits. There is ample evidence indicating that behavioral deficits produce compensatory brain activity in humans as well as other primates and mammals (Merzenich, Nelson, Stryker, Cynader, Schoppmann, and Zook, 1984; Neville, Schmidt, and Kutas, 1983; Pons, Garraghty, Ommaya, Kaas, Taub, and Mishkin, 1991) and this compensatory brain activity has resulted in compensatory growth of specific brain structures (Burnstine, Greenough, and Tees, 1984; Goldman-Rakic and Rakic, 1984). Locke (1994), in his theory of developmental language disorders, postulates that in children with delayed language, continued efforts to speak causes the recruitment of atypical right hemisphere areas to perform linguistic functions, and this compensatory activity in the right hemisphere leads to compensatory growth. In the current study, the control subjects demonstrated a larger planum temporale in the left hemisphere than in the right, while the SLI subjects demonstrated a larger planum temporale in the right hemisphere than in the left. This finding supports Locke's theory and suggests that the SLI subjects recruited the planum in the right hemisphere to help support the development of language when language development in the dominant hemisphere for some reason has been delayed or altered. A longitudinal study examining the planum temporale in language impaired children commencing at the first signs of disordered language (e.g., late onset of speech) and continuing through the end of the period of neural plasticity would need to be completed to test this theory.

Heschl's Gyrus

No significant differences in the occurrence of multiple Heschl's gyri were observed between the two groups. The lack of significant differences may be associated with the method in which Heschl's gyrus was assessed. It is possible that Heschl's gyrus was examined too far laterally to identify a difference in the frequency of the occurrence of multiple Heschl's gyri, because this phenomenon is commonly observed in the more lateral sections of the brain regardless of the subject group.

The incidence of multiple Heschl's gyri in the left hemisphere was associated with depressed semantic knowledge. Semantic knowledge was measured using a task that requires the child to determine the truthfulness of a statement presented auditorily, such as "All horses have manes." Heschl's gyrus is important for the perception of auditory stimuli because on it is located the primary auditory cortex. These findings suggest that the occurrence of multiple Heschl's gyri may affect the way auditory information is linked to lexical knowledge or meaning.

Sex Differences

Because of the small sample size and the unequal number of male and female subjects (8 males; 22 females), sex effects were not initially tested for statistical significance. However, after the individual SLI data were analyzed, it became evident that there were morphological differences between the male and female subjects, particularly with the SLI subjects. As a group, the female children in this study had a significantly smaller left temporal bank of the planum ($p < .02$) and left total planum ($p < .008$) than the male children, in addition to the significant sex differences previously reported for the area of the midsagittal section and the widths of the left and right hemispheres (see Gross Brain Measurements in Chapter 3). Inspection of individual subject data revealed that in all three of the female SLI children, but in only two of the eight male SLI children, the length of the left temporal bank of the planum was smaller than the mean length of the planum for the control children; a finding that was not related to age. It appears that these significant results are due to the three female SLI subjects who had very small cerebral hemispheres. Post hoc correlations showing strong moderate correlations between the area of the midsagittal section and language scores were not sustained after the exclusion of the three SLI females. Although further investigation of male and female subjects is needed before conclusions can be drawn, these findings suggest that female children may be less vulnerable than male children to develop a language impairment. This differential behavioral vulnerability to effects of developmental errors may account for the increased incidence of developmental language impairment in male children.

Neurobiological Bases of Language Impairment

The neuroanatomical findings of this study indicate that the areas of the brain devoted to language functioning in the left hemisphere, namely the planum temporale, the pars triangularis, and the posterior sylvian fissure, are significantly different in size and shape for children with and without developmental language impairment. The typical leftward asymmetry of the planum and pars triangularis was not found in the children with SLI. Instead, slight rightward asymmetry of the planum and pars triangularis and anomalous sylvian fissure configurations in both hemispheres were found in the SLI children. These findings support a structure-function relationship between the language structures of the brain and language ability and are consistent with previous reports that link developmental language disorders to alterations in gross brain anatomy (Plante, 1991).

It is not fully understood why such anomalies of brain morphology develop, however, cerebral asymmetries are known to appear during the third trimester of gestational development (Chi et al., 1977). During fetal life, the cells from the cerebral cortex migrate to the edge of the neural tube and form a series of areas that each process a particular kind of stimulus information. Connections are formed and stabilized between cells of adjacent areas that are simultaneously active. The axons of inactive fibers die and disappear, a process called pruning. Pruning is responsible for the development of cortical maps (in the auditory cortex, this is an orderly sequence of sound pitches). The period during which connections are formed and pruning occurs is called the "critical period" of neural plasticity because normal development will not occur without appropriate stimulation during this period.

Galaburda (1989) has proposed that atypical asymmetry of perisylvian structures may indicate an absence of the necessary developmental pruning of neural networks required for specific functions, such as language. C.M. Leonard et al. (1993) state that this failure to prune may reflect disorders in cell migration resulting from genetic or epigenetic causes.

Locke (1994) disputes the role of atypical asymmetry of the planum as a causal factor in developmental language disorder and postulates an alternative explanation of etiological factors underlying developmental language disorders. Locke (1994) suggests that the lack of typical leftward asymmetry in the brains of children with SLI and dyslexia may be the structural and functional expression of the language problem and not the cause. Locke relies on reports that suggest that the human brain is far more easily configured and reconfigured by an individual's own experience and activity and this brain activity can change the structure of the brain (Changeux and Konishi, 1987; Wolpaw, Schmidt, and Vaughan, 1991). Locke theorizes that compensatory growth of right hemisphere mechanisms are set into motion when too few utterances are available to activate left hemisphere analytic mechanisms. This compensatory use of the right hemisphere for language functions increases anatomic and functional symmetry across hemispheres in language impaired children. Our findings are consistent with Locke's theory. The SLI children had a smaller left planum temporale and pars triangularis and anomalous growth of these structures in the right hemisphere. From a neurobiological perspective, the right planum and pars triangularis are larger in the SLI children because of a failure of pruning in the right hemisphere. However, whether the occurrence of larger right hemisphere structures is the cause of or result of language impairment is not known.

Continued research in the area of brain morphology in children with SLI is necessary to fully understand the neurobiological bases of language and language impairment. In-vivo MRI studies of children with SLI have the potential to provide vital information regarding this issue. Only with this kind of research can we begin to understand why these children demonstrate difficulties in the processing and use of language. Furthermore, the search for morphological differences in the brains of language impaired individuals may provide critical information that may help differentiate among developmental language disorders, such as auditory agnosia, apraxia, hyperlexia, and dyslexia. Additionally, the use of functional MRI to study language processes has the potential to provide vital information linking anomalous cerebral anatomy to disordered language functioning.

This MRI study examining specific structures of the brain known to be involved with language functioning in children with language impairment is the first of its kind. Not only did this study include direct examination of the planum temporale, but also examination of the pars triangularis, the posterior region of the sylvian fissure, and the superior temporal gyrus. Several methodological strengths lend support to the meaningfulness of the findings reported in this study: (1) All measurers received extensive training in identifying the neuroanatomical structures and in using the measuring programs specifically developed for each structure; (2) Good inter- and intra-reliability was obtained for all measurements with conferences held to discuss any disagreements in measurements; (3) Because of the quality of the scan protocol and measuring programs and the use of sagittal images, unlike most other studies examining the planum, we were able to clearly identify Heschl's gyrus and the entire extent of the planum, thereby deriving highly reliable measurements of the temporal and parietal banks of the planum; and, (4) The expanded sylvian fissure classification system used in this study provided a specific and comprehensive description of the shape of the posterior end of the sylvian fissure.

The limitations of this study are related to the complex methodological issue of subject selection. Acquiring a homogeneous pool of SLI subjects proved to be quite a difficult task. In the two years of collecting data, a pool of only 11 subjects with language impairment was obtained and this pool consisted of subjects with language impairment ranging in severity from mild to severe. Subjects with the more severe language impairments tended to demonstrate nonverbal IQ scores below the normal range, resulting in difficulty in finding matched control children. Difficulties of this nature are not unique to this study. As previously reported, only a few studies have examined SLI children, and the one study that reported data from a sample of more than 10 subjects did not have an IQ matched control group. The difficulty in finding SLI children with "normal" IQ scores may be one reason for small sample size. Issues such as small sample size, IQ range, and the nature of the language impairment continue to be debated among the most prominent researchers of SLI and reading.

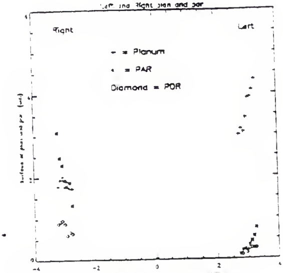
Clinical Implications

The clinical implications for this type of research are two-fold. While the use of MRI alone in diagnosing SLI is not a realistic expectation, the use of MRI in conjunction with high risk signs (i.e., family history, late onset of speech) may prove to reliably predict developmental language impairment and enable early intervention. Intervention administered early, during the critical period of neural plasticity, may facilitate neural reorganization and may lessen the effects of the language impairment. Furthermore, brain morphology research with MRI may provide parents with more definitive information on the causal factors of their children's language impairment.

APPENDIX A

PRINTOUT FROM THE PROGRAM TO MEASURE THE PLANUM TEMPORALE

05/11/35 4060 tl 195rel mecs_par



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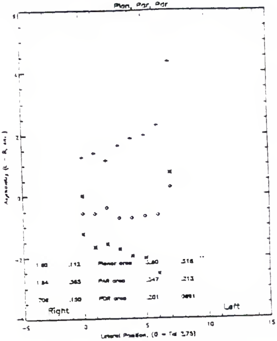

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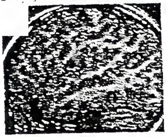

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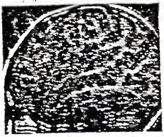

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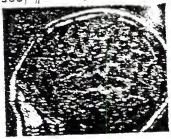
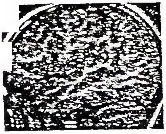
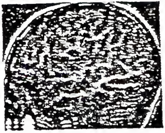
subj # = 4060. 7



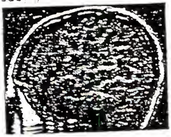
plan 1.72 cm
par 1.337 cm
Tal # = 2.74
mm lct= 43.7
subj # = 4060. 19



plan 1.77 cm
par 1.923 cm
Tal # = 2.98
mm lct= 47.5
subj # = 4060 16



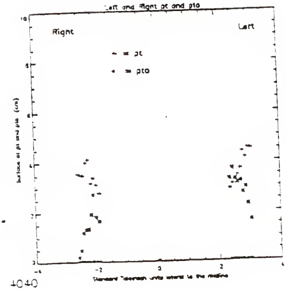
plan 1.79 cm
par 3.095 cm
Tcl # = 3.21
mm lat= 51.2
subj # = 4060 13



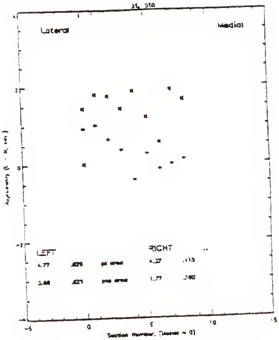
APPENDIX B

PRINTOUT FROM THE PROGRAM TO MEASURE THE PARS TRIANGULARIS

"08/08/95" 4040 lp pt/795 meas_pt_tal

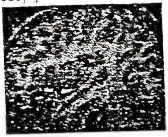


4040

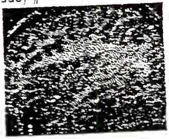


pt 3.55 cm
pta .1968 cm
Sag Pos = 2.60
mm lat= 42.1 tal=43.6
subj # = 4040 15

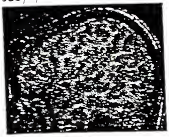
pt 4.11 cm
pto 1.332 cm
Sag. Pos = 2.26
mm lat= 36.5 tal=37.8
subj # = 4040 19



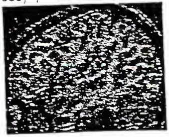
pt 2.79 cm
pto 1.646 cm
Sag. Pos = 1.91
mm lat= 30.9 tal=32.0
subj # = 4040 23



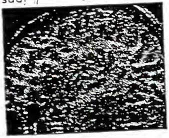
pt 4.49 cm
pta 1.540 cm
Sag. Pos = 3.04
mm lat= 49.2 tal=52.5
subj # = 4040 80



pt 3.71 cm
pto 3.212 cm
Sag. Pos = 2.69
mm lat= 43.5 tal=46.5
subj # = 4040 76

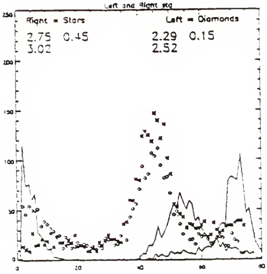


pt 2.90 cm
pta 3.298 cm
Sag. Pos = 2.34
mm lat= 37.9 tal=40.5
subj # = 4040 72

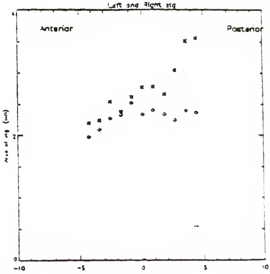


APPENDIX C
PRINTOUT FROM THE PROGRAM TO MEASURE THE SUPERIOR TEMPORAL GYRUS

05/30/95 "eg" coronal/eg.stg 4816 stg



4816

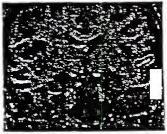


4816

Area = 1.96750 cm
Tal # = -4.23012
mmAP= -5
subj # =4816.l 61

Area = 2.32875 cm
Tal # = 0.00000
mmAP= 0
subj # =4816.l 66

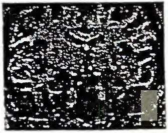
Area = 2.36312 cm
Tal # = 4.38982
mmAP= 5
subj # =4816.l 71



Area = 2.19531 cm
Tal # = -4.23012
mmAP= -5
subj # =4816.r 61

Area = 2.77531 cm
Tal # = 0.00000
mmAP= 0
subj # =4816.r 66

Area = 3.55406 cm
Tal # = 4.38982
mmAP= 5
subj # =4816.r 71



APPENDIX D

SUMMARY OF BRAIN MORPHOLOGY ASYMMETRY FINDINGS FOR CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT (SLI) (N=11)

SLI	PT	PTR	STG
1	R > L	R > L	R > L
2	R > L	R > L	L > R
3	R > L	R > L	*
4	L > R	L > R	R > L
5	L > R	L > R	L > R
6	R > L	R > L	L > R
7	R > L	R > L	R > L
8	L > R	L > R	L > R
9	L > R	L > R	L > R
10	R > L	R > L	R > L
11	L > R	L > R	R > L

PT = planum temporale (parietal and temporal bank); PTR = pars triangularis; STG = anterior superior temporal gyrus;
* Due to metal artifacts, could not measure STG from MRI scan

APPENDIX E

SUMMARY OF BRAIN MORPHOLOGY ASYMMETRY FINDINGS FOR CONTROL CHILDREN (N=19)

Control	PT	PTR	STG
1	L > R	L > R	L > R
2	L > R	R > L	R > L
3	L > R	L > R	L > R
4	L > R	R > L	R > L
5	L > R	R > L	R > L
6	L > R	R > L	R > L
7	L > R	L > R	R > L
8	L > R	L > R	R > L
9	L > R	L > R	L > R
10	L > R	L > R	L > R
11	L > R	L > R	L > R
12	R > L	L > R	R > L
13	L > R	L > R	R > L
14	L > R	L > R	L > R
15	L > R	R > L	L > R
16	R > L	L > R	L > R
17	L > R	L > R	R > L
18	L > R	R > L	R > L
19	L > R	L > R	R > L

PT = planum temporale (parietal and temporal bank); PTR = pars triangularis; STG = anterior superior temporal gyrus

APPENDIX F

SUMMARY OF CLASSIFICATION FINDINGS FOR THE SYLVIAN FISSURE IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT (SLI) (N=11)

		Sylvian Fissure Classification Types										
SLI		L	T	TA	S	F	H	V	M	BI	PB	MH
1	LH	+	+	-	-	+	-	+	-	-	+	+
	RH	-	-	-	-	-	-	+	-	+	-	+
2	LH	-	+	-	+	+	+	+	-	-	-	+
	RH	-	-	-	-	+	-	+	-	+	-	+
3	LH	-	-	-	-	+	-	+	+	-	-	+
	RH	-	-	+	+	-	+	-	-	+	+	+
4	LH	-	+	-	-	+	-	-	-	+	+	-
	RH	+	-	-	-	-	-	-	+	+	-	-
5	LH	-	-	+	-	-	+	-	-	-	+	+
	RH	-	-	+	+	-	-	+	+	+	-	+
6	LH	+	-	+	-	-	+	-	+	-	-	-
	RH	+	-	+	-	-	-	-	+	-	-	-
7	LH	-	+	+	-	+	-	-	-	-	+	-
	RH	-	-	-	-	+	-	+	+	+	-	-
8	LH	-	+	+	-	-	-	-	-	+	+	+
	RH	+	-	-	-	-	+	-	-	-	-	-
9	LH	-	-	-	-	+	+	-	-	-	+	-
	RH	-	+	-	-	+	-	+	-	+	-	+
10	LH	+	-	+	-	+	-	-	+	+	-	-
	RH	-	-	-	-	+	-	+	+	+	-	+
11	LH	+	+	+	+	+	-	-	-	-	-	-
	RH	-	-	-	-	+	-	+	+	+	-	+

LH = left hemisphere; RH = right hemisphere; + = Occurence of this fissure type on at least one sagittal section; - = Absence of this fissure type on all sagittal sections analyzed; Normal fissures = L, T, TA, and S; Anomalous fissures = F, H, V, and M; each SLI had bilateral anomalous fissures

APPENDIX G
SUMMARY OF CLASSIFICATION FINDINGS FOR THE SYLVIAN FISSURE IN CONTROL CHILDREN (N=19)

Control		Sylvian Fissure Classification Types										
		L	T	TA	S	F	H	V	M	BI	PB	MH
1	LH	-	-	+	-	-	+	-	-	-	-	-
	RH	-	-	-	-	+	-	+	-	+	-	+
2	LH	+	-	+	-	+	-	-	-	+	+	-
	RH	+	-	+	-	+	-	-	-	+	-	+
3	LH	-	+	-	+	-	-	+	-	+	+	-
	RH	-	-	-	+	+	+	+	-	-	-	+
4	LH	+	-	+	-	+	-	-	-	+	+	-
	RH	+	-	-	-	-	-	-	-	-	-	+
5	LH	+	-	+	-	-	-	-	-	+	+	+
	RH	+	-	-	+	-	-	+	-	+	-	-
6	LH	+	-	+	-	-	-	-	-	+	+	-
	RH	+	-	-	-	-	-	-	-	-	-	-
7	LH	-	-	+	-	-	-	-	-	+	+	+
	RH	+	-	-	+	-	-	-	-	+	-	-
8	LH	-	+	+	+	-	-	-	+	+	+	-
	RH	+	+	+	+	-	-	-	-	-	-	-
9	LH	-	+	-	-	+	-	+	-	-	+	-
	RH	-	-	-	-	+	-	+	-	+	-	+
10	LH	-	+	-	+	-	-	-	-	-	+	-
	RH	+	-	-	+	-	-	-	+	-	-	-
11	LH	-	+	-	-	+	+	+	+	+	-	+
	RH	-	-	-	-	+	-	+	-	+	-	+
12	LH	+	-	-	-	+	-	+	-	+	-	+
	RH	+	-	-	-	-	-	-	-	-	-	+
13	LH	-	+	+	+	-	-	-	+	-	+	-
	RH	+	+	+	-	+	-	-	-	+	+	-
14	LH	+	-	-	+	-	-	-	+	-	-	-
	RH	+	-	-	+	-	-	+	-	+	-	-
15	LH	+	-	+	-	-	-	-	-	+	-	+
	RH	+	-	+	-	-	-	-	-	-	-	+
16	LH	-	-	-	-	-	-	+	-	+	-	+
	RH	+	+	-	+	-	-	-	-	+	-	+
17	LH	-	+	+	-	-	+	-	-	-	+	-
	RH	+	-	-	+	-	-	+	-	+	-	+
18	LH	-	+	+	+	-	-	-	+	-	-	+
	RH	+	-	+	+	-	-	-	-	-	-	+
19	LH	-	+	+	-	+	+	-	+	-	+	-
	RH	+	-	-	-	-	-	-	-	+	-	+

LH = left hemisphere; RH = right hemisphere; + = Occurence of this fissure type on at least one sagittal section; - = Absence of this fissure type on all sagittal sections analyzed; Normal fissures = L, T, TA, and S; Anomalous fissures = F, H, V, and M; Each SLI had bilateral anomalous fissures

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BIOGRAPHICAL SKETCH

Laurie Rose Mercado was born in Miami, Florida, on July 24, 1964. She earned a Bachelor of Arts degree from the University of Florida in May of 1987 and a Master of Arts degree in speech-language pathology from the University of Florida in May of 1989. Upon completion of her studies, she moved to South Florida and worked for the Broward County School Board for three years. Ms. Mercado returned to the University of Florida in August of 1992 to begin her doctoral studies and will receive a Doctor of Philosophy degree in December of 1995. In January of 1996, Ms. Mercado will marry and move to Germany. There she intends to continue research in the area of brain morphology at the University of Munich.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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